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HASTINGS IGLOO HAZARDS TESTS FOR SMALL EXPLOSIVE CHARGES

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Full-scale field tests have been conducted to characterize the hazards to an exposed site when limited quantities of bulk explosives, positioned inside igloo magazines, are statically detonated. Specific test objectives were to (1) determine the explosive quantity which, when detonated inside a standard-size, earth-covered magazine, produces no significant external effect and (2) evaluate the dispersal of structure debris and measure external airblast for the range of explosive quantities from that marginally contained up to 68 Kg (150 lb).

Test results in the form of overall structural response, airblast measurements and hazardous fragment distributions are provided for selected explosive charge weights from 5.4 Kg (12 lb) to 68 Kg (150 lb).

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I. INTRODUCTION

In 1979 the Ballistic Research Laboratories (BRL) conducted a series of full-scale field tests* designed to characterize the hazards to an exposed site when either 68 Kg (150 lb) or 206 Kg (450 lb) TNT charges, positioned inside earth-covered reinforced concrete igloos, were statically detonated. Test results took the form of airblast profiles and concrete fragment distributions in terms of densities, weights, and their locations relative to igloo orientation. These tests were conducted at the NAVAJO Depot Activity near Flagstaff, Arizona, where excess igloos, constructed in 1942 according to U.S. Army specifications, were made available for destructive tests.

While the Flagstaff tests were conducted to support a hazards analysis at a particular site, they have also been used to support changes in the "Manual on NATO Safety Principles for the Storage of Ammunition and Explosives" that requires a minimum distance of 400 metres between inhabited buildings and igloos containing Hazard Division 1.1 ammunition or explosives. No minimum net explosive quantity is associated with this 400-metre restriction.

The conclusions reached in the Flagstaff tests were:

1. The 400-metre minimum distance requirement between inhabited buildings and igloos containing Hazard Division 1.1 ammunition or explosives is excessive for small explosive weights. This is true for both fragment and peak overpressure hazards.

2. The use of a barricade in front of the headwall and a re-design of the vent stack at the rear of the igloo would have reduced the density of hazardous fragments to an insignificant level.

3. The peak overpressure and fragment hazards to the sides and rear of earth-covered igloos are significantly less than those to the front for relatively small explosive weights. These directional effects should be considered when establishing minimum distance requirements.

The Flagstaff tests have been supplemented with additional full-scale tests designed to (1) determine the explosive quantity which, when detonated inside a standard-size, earth-covered igloo, produces no significant external effect and (2) evaluate the concrete fragment and external airblast hazards for a range of explosive quantities from that marginally contained, up to 68 Kg (150 lb).

All tests were sponsored by the Department of Defense Explosives Safety Board.

A description of these tests, test results and analysis are presented in the following sections.

**P. Howe, H. Reeves, and O. Lyman, "An Approach to Munitions Storage Applicable to the McNair Compound of the Berlin Brigade," ARBRL-SP-00013, Ballistic Research Laboratory, September 1979 (AD C019277L).*

II. DESCRIPTION OF TESTS

All tests were conducted at the Nebraska State National Guard Weekend Training Site near Hastings, Nebraska, where a total of twelve excess igloo magazines were made available for destructive tests in support of this effort. This site is part of an abandoned Navy Ammunition Depot that was constructed during WW II. All of the igloos exhibited structural failures in the form of hairline cracks in the sidewalls, arch crest, backwall, and headwall. The igloos were constructed according to US Navy specifications and were designed to be earth-covered to a depth of at least 0.6 m (2 ft). Erosion of the earth-cover was observed in many cases due to a lack of maintainance. All of the magazines were weed-covered up to a height of 0.9 m (3 ft). The magazine headwalls faced an earth-backed concrete blast shield. The distance between the vertical headwalls and the blast shields varied between 3.7 m (12 ft) at the base to 3.7 m (15 ft) at the top. See Figures 1 through 3.

Pre-test site preparation included cutting the grass in front of the magazines out to a distance of 150 m (500 ft). The width of this cleared recovery area varied due to the presence of an elevated access road on the right side of the igloos. See Figure 4. The grass was cut out to the road on the right side. The cleared area on the left side of the igloos was essentially infinite. These recovery areas were searched after each test, and concrete fragments weighing at least 0.18 Kg (0.4 lb) were catalogued in terms of numbers per discrete weight groups and their location relative to the front of the igloo. A postage scale was used to establish fragment weights up to 0.9 Kg (2 lb). The weights of heavier fragments were estimated.

Two high-speed (500 fps) 16 mm cameras were positioned to the side of the headwalls to monitor initial headwall fragment velocities. Air blast parameters were monitored by pressure transducers, flush mounted, via teflon collars, to lead blocks positioned to the sides and fronts of the igloos. A cleared path from the headwall to the pressure transducers was prepared using a front-end loader to remove vegetation and level the ground. See Figure 5. The data-gathering instrumentation system is shown in Figure 6.

Standard 3.36 Kg (8 lb) blocks of TNT, with a small C4 booster charge, were positioned inside the igloos and statically detonated using long lengths of mild detonating fuze activated with electrically sensitive detonators. The position of the TNT charge was deliberately varied, in those tests involving 5.44 Kg (12 lb) charges, to determine the influence of charge location on incipient headwall failure.

III. RESULTS AND OBSERVATIONS

The tests results are presented in three catagories: structural response, external airblast, and hazardous fragment distributions; and each are discussed in the following sections.

A. Structural Response

The test results in terms of structural response are presented in Table 1 and Figures 7 through 15.

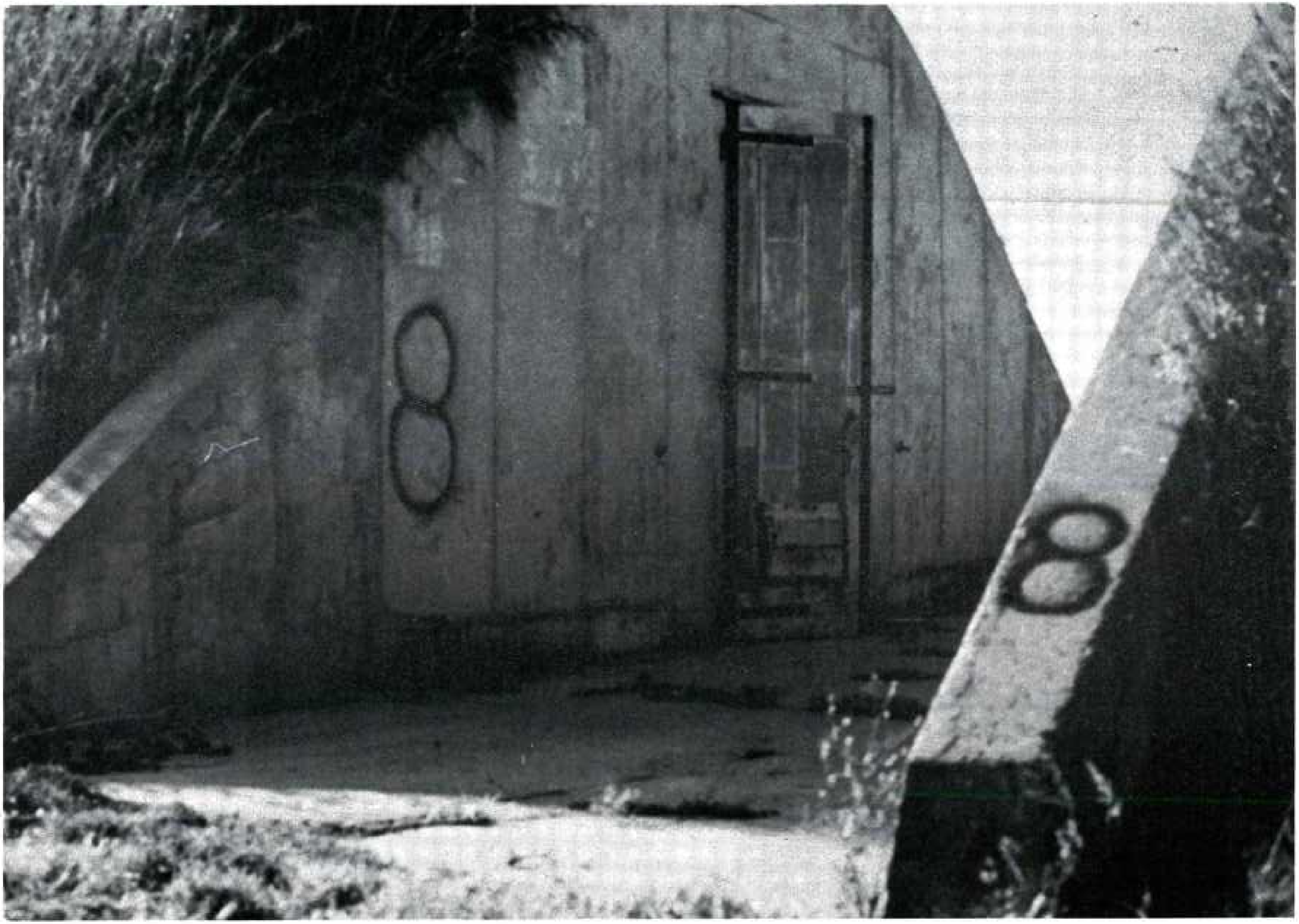

Figure 1. Oblique View of Igloo Magazine with Blast Shield

Figure 2. Side View of Igloo Magazine Headwall, Blast Shield and Access Road

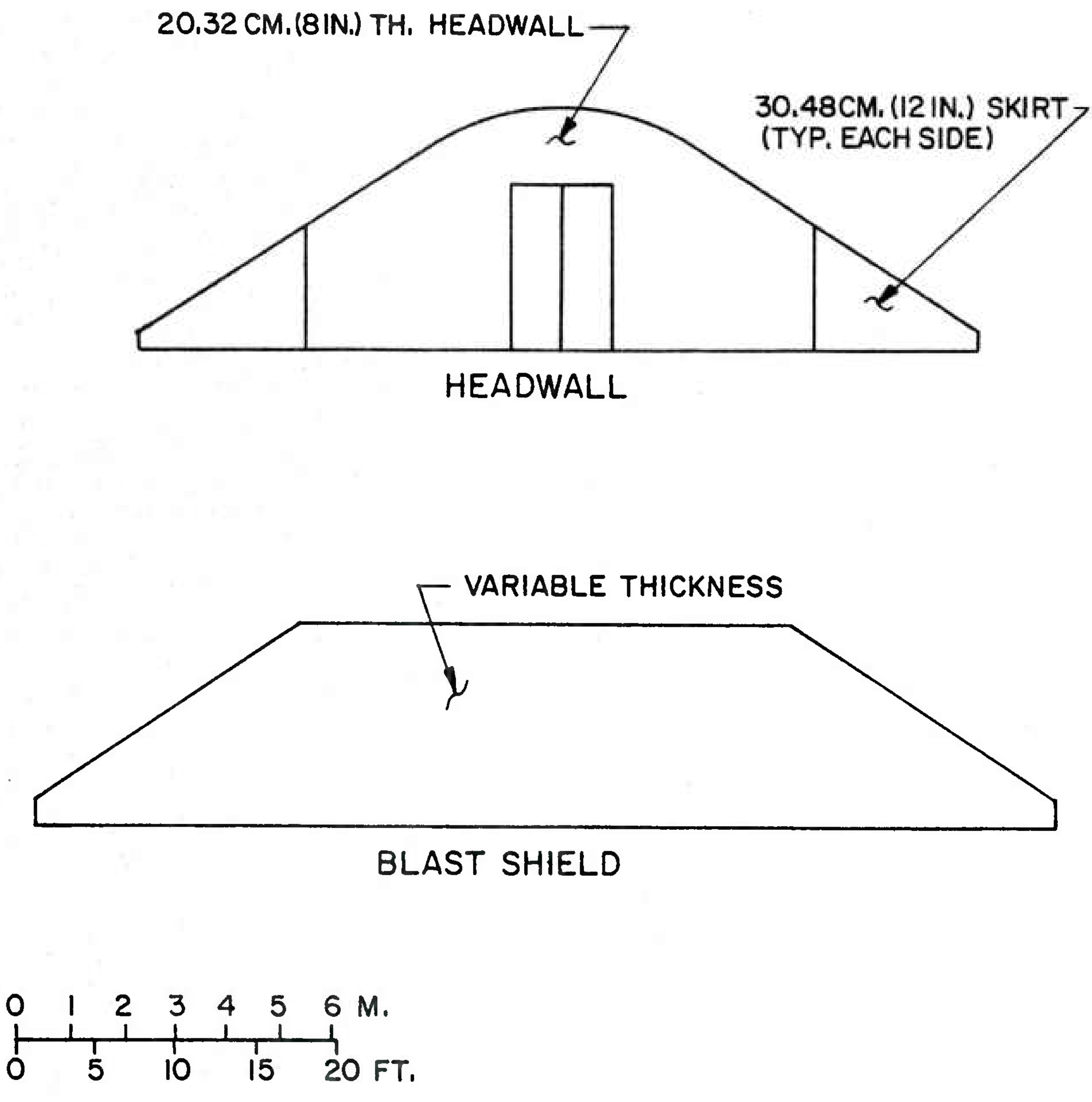

Figure 3. Schematic Drawing of Igloo Magazine and Blast Shield

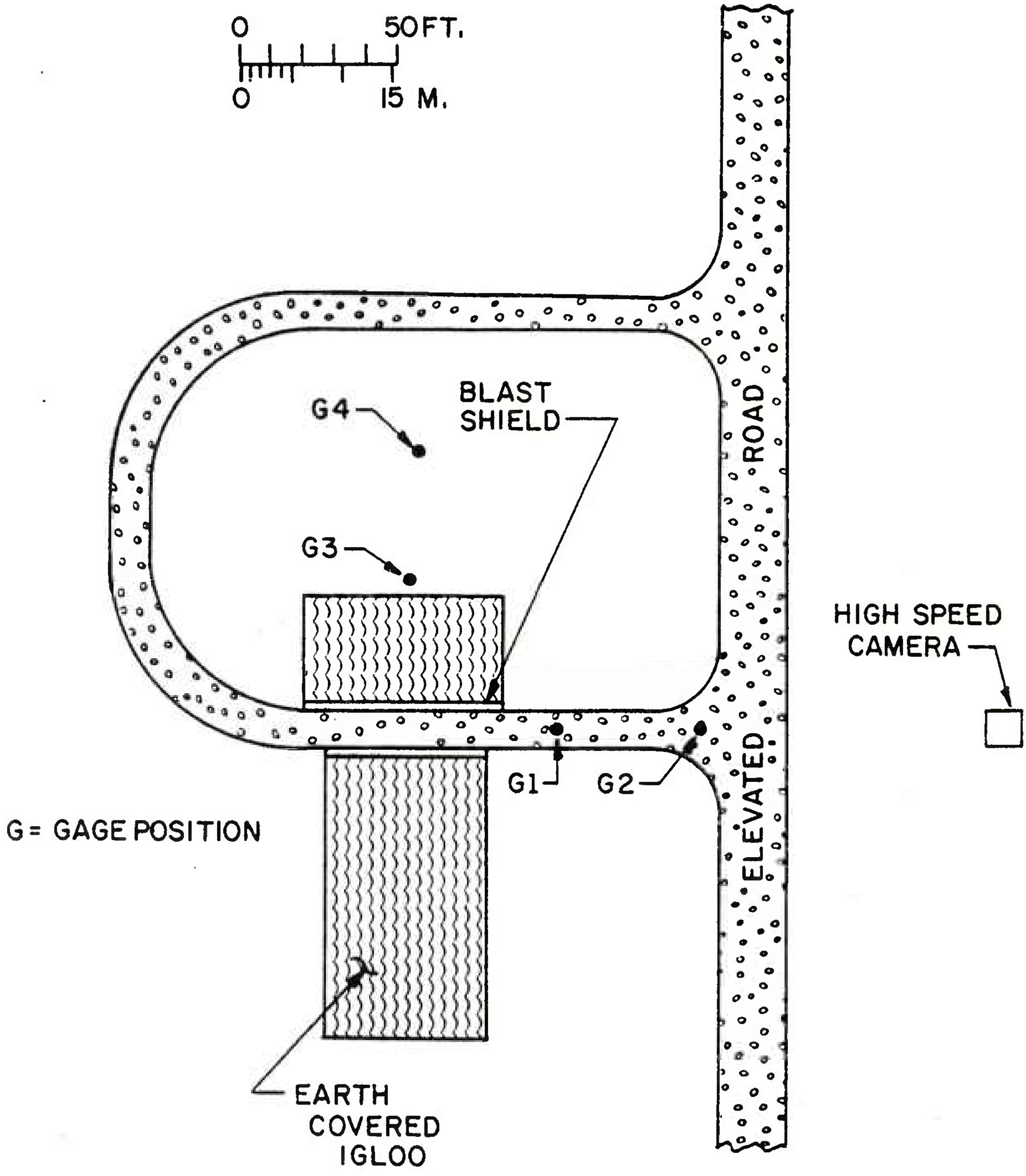

FIGURE 4. TEST LAYOUT SHOWING LOCATION OF IGLOO, BLAST SHIELD, ROADS AND INSTRUMENTATION

Figure 5. Rear View of Blast Shield Showing Cleared Path for Pressure Transducers

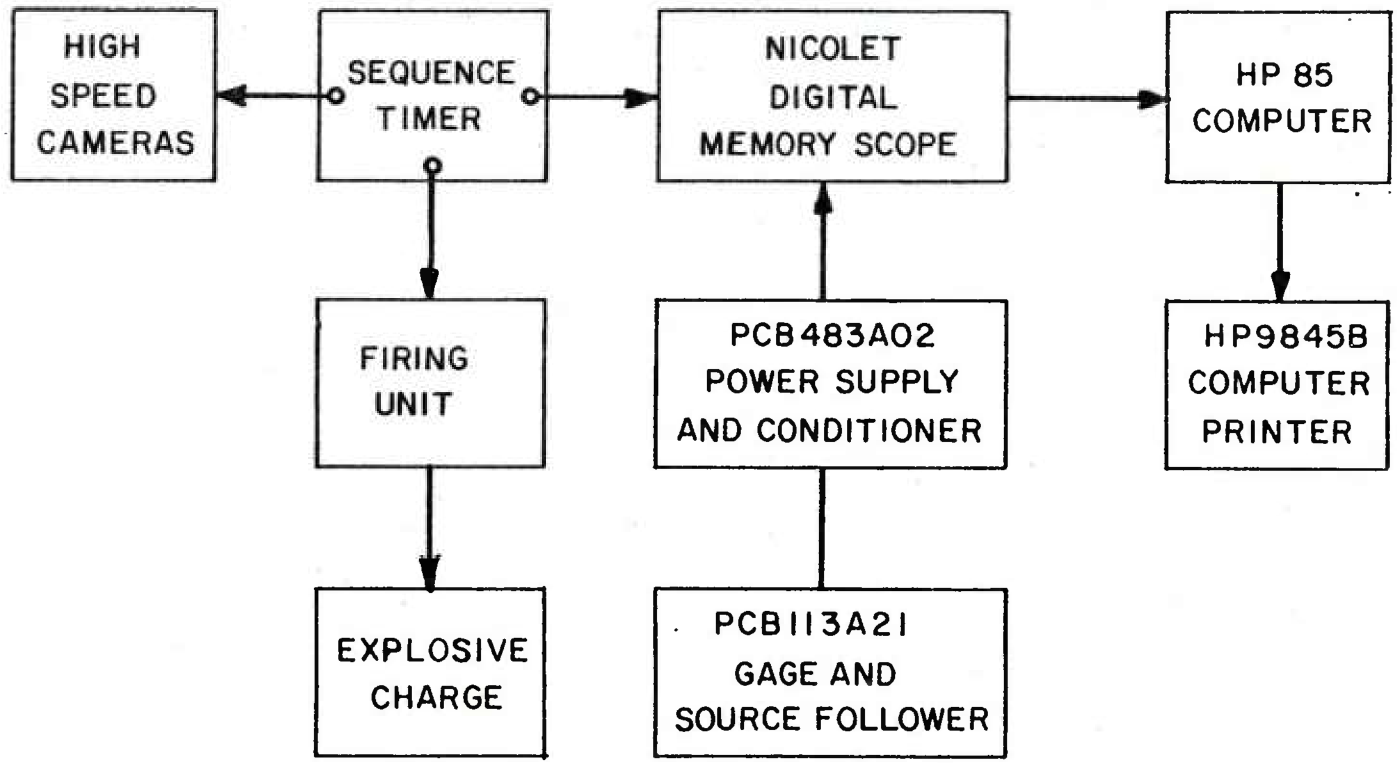

FIGURE 6. INSTRUMENTATION SYSTEM

Table 1. Test Results - Explosive Charges Positioned Inside Earth-Covered Igloo Magazines

Test No.	Charge Wgt.	Charge Position	Remarks
1	18 Kg (40 lb)	4 m (13 ft) from headwall	Headwall failed. Approximately 50% of the arch crest and 35% of the sidewalls in the front and rear of the igloo destroyed. All debris from arch crest and sidewall recovered on the floor of the igloo. Large center section of the igloo remained standing. Some debris from headwall scattered along entrance roadway after bouncing off blast shield. One large piece (5.4 Kg) of concrete from headwall cleared blast shield and recovered 40 metres in front of the headwall. Parts of terra cotta vent stack scattered up to 10 metres from the rear of the magazine. The wood core and metal sheathed doors were destroyed and recovered between headwall and blast shield. See Figure 7.
2	11 Kg (24 lb)	4 m (13 ft) from headwall	Headwall failed. Arch crest cracked and displaced. Forward section of left sidewall failed. See Figure 8. A total of nine concrete fragments weighed in excess of 4 Kg. The remainder of the fragments weighed between 0.5 Kg and 2.0 Kg. A large piece of the door (9Kg) recovered 30 metres to the right and 7 metres behind the headwall.
3	5.4 Kg (12 lb)	4 m (13 ft) from headwall	There was a large crack in the face of the headwall. The headwall was still in one piece and standing in place. See Figure 9. The right side door recovered 15 metres from the center of the headwall on the right side. The left side door recovered 30 metres from the center of the headwall on the left side.

Table 1. Test Results - Explosive Charges Positioned Inside Earth-Covered Igloo Magazines (Continued)

Test No.	Charge Wgt.	Charge Position	Remarks
4	5.4 Kg (12 lb)	4 m (13 ft) from headwall	The headwall separated from the sidewall and exhibited several large cracks. The headwall was still standing and held together by rebar. See Figure 10. The right door recovered 24 metres from the center of the headwall. The left door recovered 49 metres from the center of the headwall on the left side.
5	5.4 Kg (12 lb)	4 m (13 ft) from headwall	The headwall failed and separated into several large pieces, however, the headwall held in place by rebar. See Figure 11. The left door, almost intact, recovered 40 metres from the center of the headwall on the left side. The right door recovered in one piece 56 metres on the right side.
6	5.4 Kg (12 lb)	4 m (13 ft) from rear wall	The headwall failed completely, separated from the sidewall, and fractured into several large pieces. The left door recovered 31 metres to the side and 15 metres to the rear of the headwall. The right door recovered 27 metres to the side and 1.8 metres to the rear of the headwall. See Figure 12.
7	7.3 Kg (16 lb)	4 m (13 ft) from headwall	A 6 metre (20 ft) long section of the right rear sidewall remained standing. The remainder of sidewall and headwall was destroyed. A large piece of the left door recovered 37 metres to the left side of the igloo. A large section of the right door recovered 12 metres to the right side. Four large pieces of concrete, all approximately 9 Kg, recovered on the rear side of the blast shield earth fill. See Figure 13.

Table 1. Test Results - Explosive Charges Positioned Inside Earth-Covered Igloo Magazines (Continued)

Test No.	Charge Wgt.	Charge Position	Remarks
8	5.4 Kg (12 lb)	4 m (13 ft) from rear wall	Headwall failed and fractured into several large pieces. A large crack in arch crest entire length of the igloo. Several large cracks in the sidewall on each side. Further examination was not possible as igloo was in imminent danger of collapsing. Large pieces of right door recovered 30 metres to the side and 18 metres and 24 metres to the rear of the headwall. Large pieces of left door recovered 24 metres and 40 metres to the the side and 24 metres to the rear of the headwall. One other piece of left door recovered 61 metres from the headwall on the left side. See Figures 14 and 15.
9	45.4 Kg (100 lb)	Center of the igloo	The igloo was completely destroyed. Concrete fragments recovered out to a distance of 149 metres.
10	68 Kg (150 lb)	Center of the igloo	The igloo was completely destroyed. Concrete fragments recovered out to a distance of 244 metres.
11	36 Kg (80 lb)	Center of the Igloo	The igloo was completely destroyed. Concrete fragments recovered out to a distance of 143 metres.
12	27 Kg (60 lb)	Center of the igloo	The igloo was completely destroyed. Concrete fragments recovered out to a distance of 110 metres.

Figure 7. Test Results - Test No. 1, 18 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall

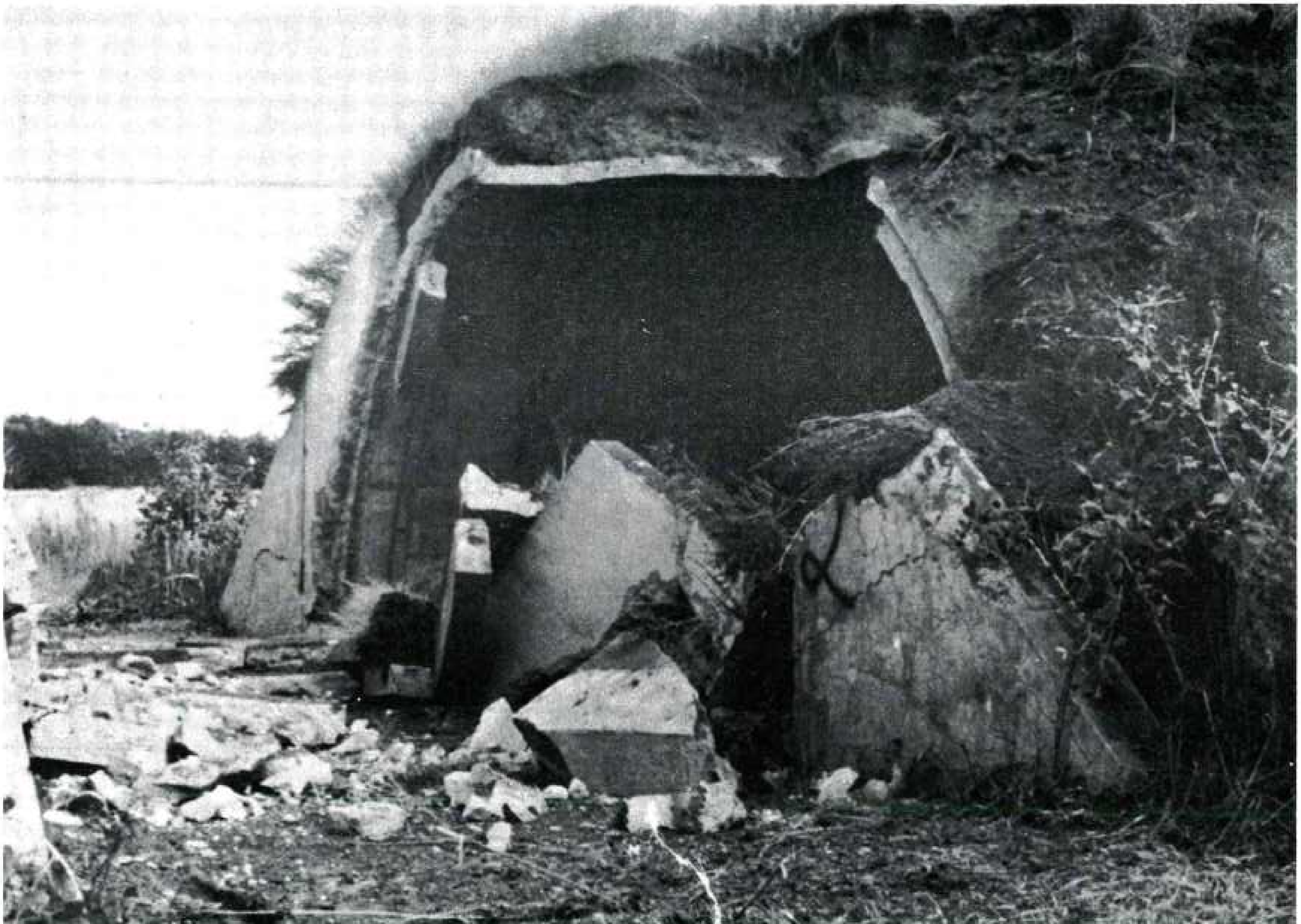

Figure 8. Test Results - Test No. 2, 11 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall

Figure 9. Test Results - Test No. 3, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall

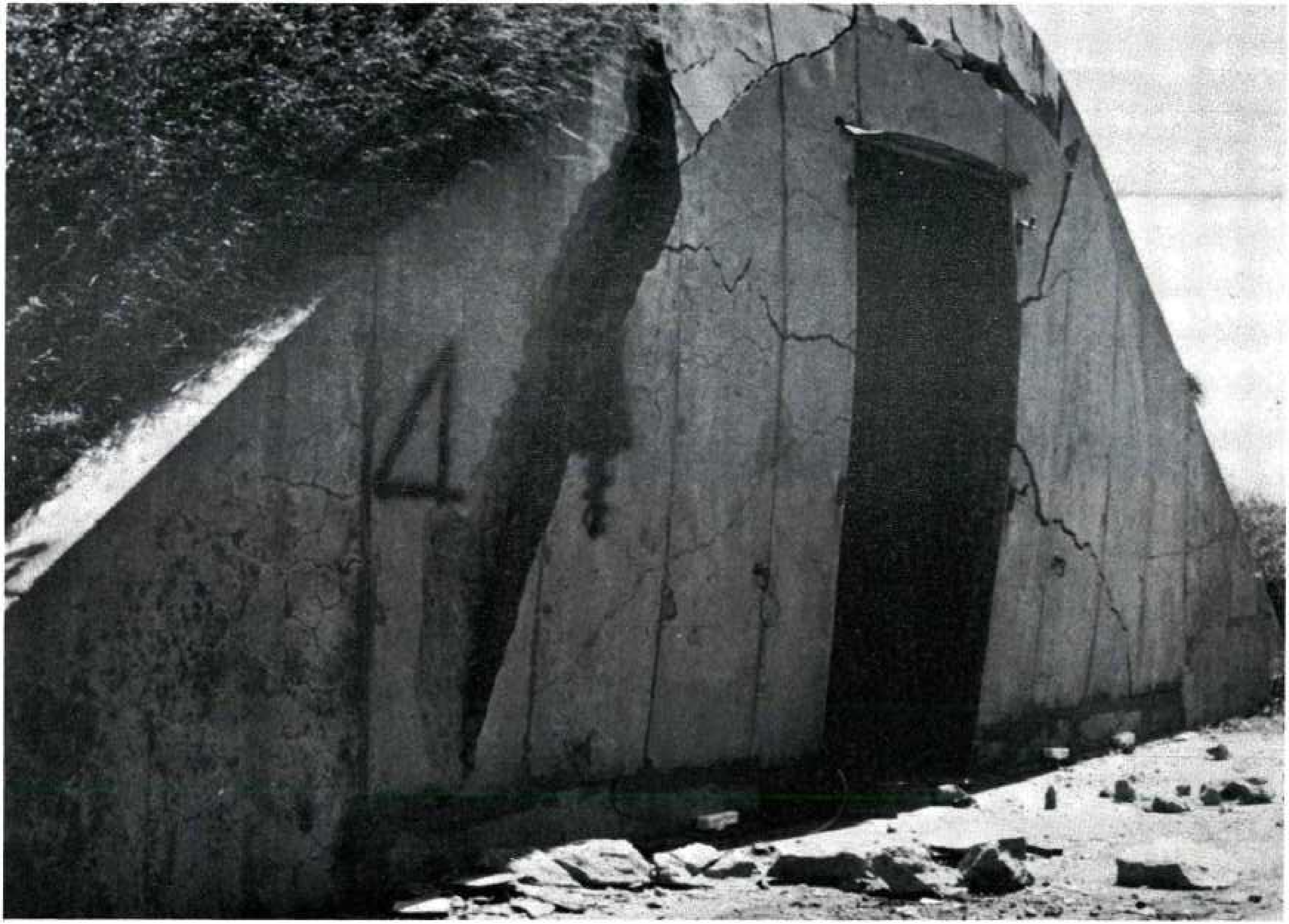

Figure 10. Test Results - Test No. 4, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall

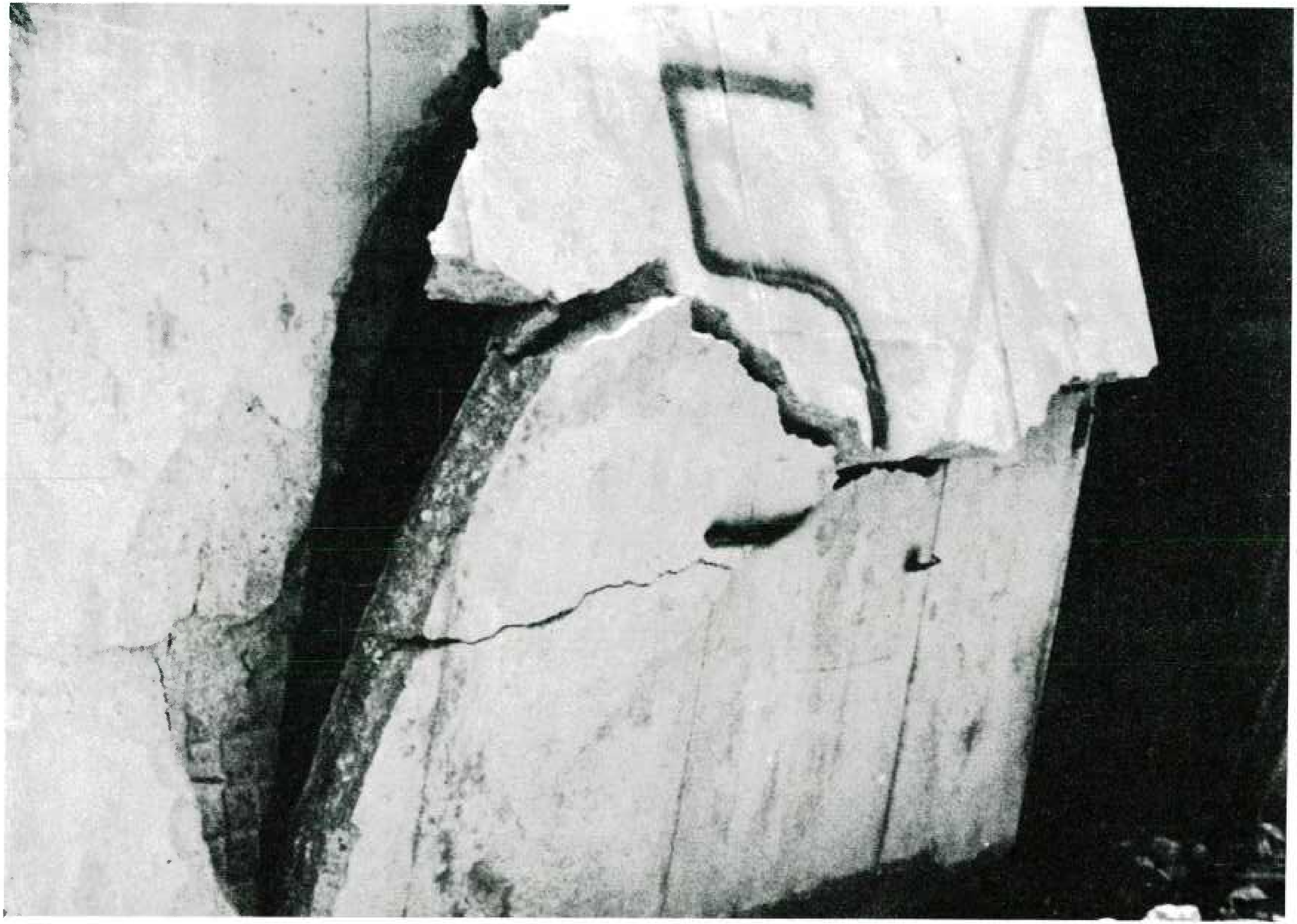

Figure 11. Test Results - Test No. 5, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall

Figure 12. Test Results - Test No. 6, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Headwall

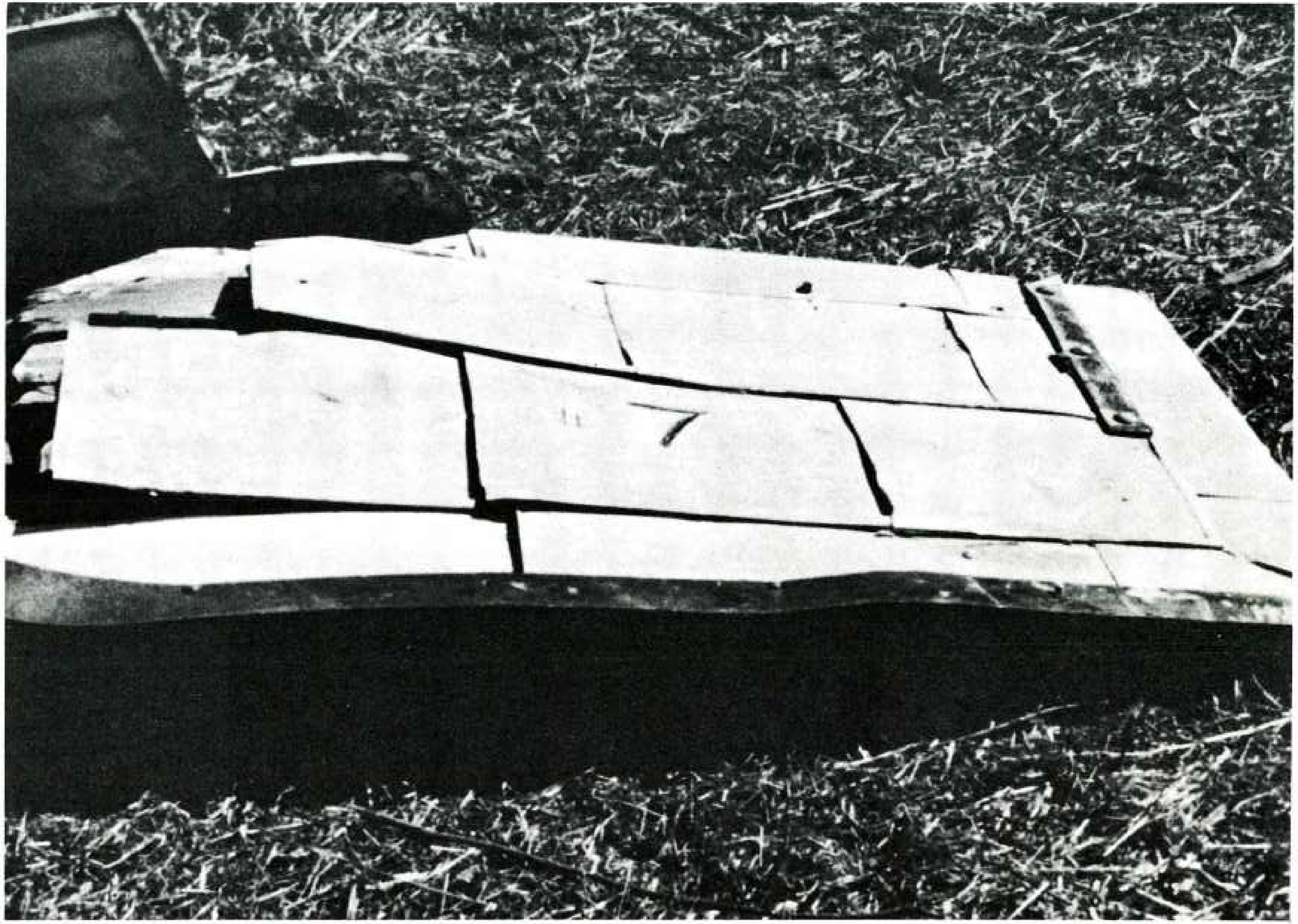

Figure 13. Test Results - Test No. 7, 7.3 Kg TNT Charge
Positioned Inside Magazine 4 Metres from Headwall

Figure 14. Test Results - Test No. 8, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Rearwall

Figure 15. Test Results - Test No. 8, 5.4 Kg TNT Charge Positioned Inside Magazine 4 Metres from Rearwall

While the results of Tests 3,4, and 5 (5.4 Kg charge positioned 4 metres from the headwall) are observably different, the differences in terms of structural response are not significant and could be explained in terms of variations in the structural integrity of these 40-year old magazines.

The complete headwall failures observed in Tests 6 and 8, where the 5.4 Kg charge was positioned 4 metres from the rearwall, were different in terms of structural response from the results of Tests 3, 4, and 5. However, these differences had little or no effect in defining hazardous distances. When the headwalls failed in Tests 6 and 8, they fractured into large pieces that were recovered in front of the blast shield. (See Figures 12 and 15.) The real hazards in the 5.4 Kg test series were the doors that were thrown clear of the area between the headwall and the blast shield after bouncing off the blast shield.

The inconsistency observed between the results of Tests 1, 2, and 7, where a 7.3 Kg charge produced more severe structural damage than either an 11 Kg or 18 Kg charge, can only be explained in terms of unobservable differences in the condition of the magazines before testing.

As expected, charge weights in excess of 27 Kg completely destroyed the magazines.

B. External Airblast Measurements

Peak overpressure, impulse, and time-of-arrival measurements are presented in tabular form in Table 2. The individual pressure-time history records are presented in Appendix A. Instrumentation was not available for Tests 1, 9, and 10. Data for Test 3 was lost due to equipment malfunction.

There were no hazardous overpressures measured in any of these tests. While some of the pressure-time history records were difficult to read due to low pressure levels and non-classical shapes, they are mutually supporting.

It is of interest to note that the pressure-time histories recorded for explosive charge weights up to 10.9 Kg were apparently reflected shock pressure-time histories; i.e., the incident shock removed the doors allowing the shock wave that was reflected off the rear wall to escape unimpeded. The presence of the reflected shock wave was verified photographically and explains the apparent anomaly in the time-of-arrival measurements recorded in those tests where the 5.4 Kg charge was positioned near the rear wall. No reflected shock wave was observed in the 45.4 Kg and 68 Kg charge weight tests where the entire igloo was destroyed rapidly, allowing pressure to vent upward. The pressure-time histories recorded for these tests were from the incident wave.

C. Hazardous Fragment Distributions

The results of the fragment collection effort for those tests with charge weights between 27 and 68 Kg, positioned in the center of the magazines, are presented in Table 3 in terms of hazardous fragment densities per 600 $ft.^2$

Table 2. Peak Overpressure, Impulse and Time of Arrival from TNT Charges Statically Detonated Inside Igloo Magazines

TNT Charge Weight		TNT Charge Position[a]		Gage Position[b]		Pressure		Impulse		TOA
Kg	lb	m	ft	m	ft	psi	kPA	psi-msec	kPA-msec	msec
				24.3F	80	0.5	3.4	Lost		161
				27.4F	90	0.4	2.8	Lost		168
10.9	24	4	13	18.3S	60	0.76	5.2	3.75	25.9	160
				27.4S	90	0.55	3.8	2.59	17.9	167
				18.3F	60	1.0	6.9	9.85	67.9	69
45.4	100	12	40	27.4F	90	0.7	4.8	7.78	53.7	95
				15.2S	50	1.2	8.3	8.55	59.0	62
				27.4F	90	0.74	5.1	4.11	28.3	92
68.0	150	12	40	18.3F	60	1.41	9.7	13.46	92.8	66
				27.4F	90	1.23	8.5	9.94	68.6	92
				15.2S	50	1.53	10.6	8.83	60.9	60
				27.4F	90	1.07	7.4	7.21	49.7	86

a. Distance measured from the headwall to where the TNT charge was positioned inside the igloo.

b. Distance measured from the center of the headwall to where the gage was positioned. F= in front of the headwall. S= to the side of the headwall.

Table 2. Peak Overpressure, Impulse and Time of Arrival from TNT Charges Statically Detonated Inside Igloo Magazines (Continued)

TNT Charge Weight		Position[a]		Gage Position[b]		Pressure		Impulse		TOA
Kg	lb	m	ft	m	ft	psi	kPA	psi-msec	kPA-msec	msec
5.4	12	4	13	18.3F	60	0.4	2.8	4.69	32.2	Lost
				18.3F	60	0.62	4.3	4.83	33.3	147
				27.4F	90	0.46	3.2	3.27	22.6	172
5.4	12	4	13	15.2S	50	0.67	4.6	5.52	38.1	132
				27.4S	90	0.34	2.3	3.06	21.0	168
				18.3F	60	0.16	1.1	0.53	3.7	110
				27.4F	90	0.25	1.7	1.73		135
5.4	12	20.4	67	15.2S	50	0.39	2.7	1.91	13.2	97
				27.4S	90	0.23	1.6	1.10	7.6	134
				18.3F	60	0.36	2.5	2.87	19.6	114
5.4z	12z	20.4	67	27.4F	90	0.33	2.3	1.05	7.2	139
				15.2F	50	0.69	4.8	2.37	16.3	100
				27.4S	90	0.27	1.9	1.05	7.2	135
				18.3F	60	0.49	3.4	4.03	27.8	138
7.3	16	4	13	27.4F	90	0.34	2.3	2.50	17.2	163
				15.2S	50	0.51	3.5	3.24	22.3	138
				27.4S	90	0.35	2.4	2.36	16.3	166

a. Distance measured from the headwall to where the TNT charge was positioned inside the igloo.

b. Distance measured from the center of the headwall to where the gage was positioned. F= in front of the headwall. S= to the side of the headwall.

for the discrete angular and distance increments.* These distributions were generated by averaging all the fragment data for a given test when fragment data from both the right and left side recovery areas was available. When fragment data from only one side was available, symmetry was assumed. These distributions do not reflect the uneven distribution observed in some of these tests where the number of fragments recovered on the left side of the recovery area was greater than that recovered on the right. These skewed distributions are assumed to be an anomaly.

Exponential density functions for these tests were generated using the density distributions in Table 3 to compare predicted and observed densities, per 600 $ft.^2$, independent of angle; i.e., the highest density value for a given distance increment was used in the calculation. See Figures 16 through 19. Fragment density distributions at distances less than 53 metres were not used due to the masking effect of the blast shield.

The raw field recovery data is provided in Appendix B for each fragment in terms of its position and weight group. Only those fragments weighing at least 0.18 Kg (0.4 lb) were considered hazardous. While all of the fragments, weighing in excess of 0.18 Kg, for a given test were combined in arriving at hazardous density distributions, their segregation into weight groups, in Appendix B, has been preserved for future reference.

Attempts to measure initial headwall fragment velocities photographically were unsuccessful. The field of view between the headwalls and blast shields was obscured by combustion products and other debris before the headwalls failed and before the doors hit the blast shields. However, estimates of initial door velocities and the times of arrival of the reflected shock waves, between the headwalls and blast shields, were taken from the high speed films and are provided in Table 4. The door velocity estimates are crude. The exact time that the doors hit the blast shield can only be estimated, and it is not known if the doors were accelerating when they impacted the blast shield.

There is good agreement between the time-of-arrival measurements of the reflected shock wave obtained photographically and those obtained from the pressure transducers.

IV. DISCUSSION

The maximum explosive quantity which, when detonated inside the standard-size, earth-covered magazines used in this series of tests, produces no significant external effect was not determined due to door separation. These large wood core doors were attached to the headwalls by three hinges that failed rapidly under all test conditions. The doors were observed impacting the blast shields and were recovered in areas off the side of the magazines. It is

**The origin of the coordinate system used in generating these distributions was the front of the igloo.*

Table 3. Test Results - Hazardous Fragment Densities per 600 ft^2 for Discrete Angular and Distance Increments

Distance		27 Kg (60 lb) Test			36 Kg (80 lb) Test			45 Kg (100 lb) Test			68 Kg (150) Test		
M	Ft.	0-5°	5-10°	10-45°	0-5°	5-10°	10-45°	0-5°	5-10°	10-45°	0-5°	5-10°	10-45°
31	100	6.3	4.7	9.0	0	0	2.8	0	0	3.5	3.1	2.4	3.8
38	125	24.3	21.9	26.8	0	0.6	2.1	0	2.4	3.1	0	3.0	6.1
46	150	19.9	10.0	7.1	10.0	10.5	3.8	23.8	18.8	9.3	21.9	12.5	9.5
53	175	40.4	25.0	23.2	28.6	16.8	4.6	16.8	15.8	8.5	10.2	5.9	3.2
61	200	19.4	12.7	6.3	20.4	13.2	4.2	3.0	8.0	6.9	19.1	12.5	6.4
69	225	18.0	9.7	4.7	15.5	10.7	7.0	0	5.8	1.4	3.9	3.8	2.6
76	250	20.7	13.3	3.1	18.4	10.9	2.9	20.8	15.0	4.1	1.2	1.2	1.1
84	275	10.4	6.3	1.8	4.1	3.1	1.2	2.0	4.1	2.1	7.2	6.2	1.6
91	300	2.0	1.5	0.3	11.4	6.6	2.4	3.8	3.6	1.1	5.8	4.8	1.8
99	325	1.8	2.2	1.1	0.9	1.3	1.9	3.6	3.1	0.9	4.5	2.9	0.8
107	350	1.6	0.8	0.6	2.4	1.6	3.2	0	0.4	0.7	4.8	4.6	2.3
114	375	1.5	0.8	0.2	3.0	1.5	0.8	0	1.1	2.5	9.9	5.5	1.3
122	400	0	0	0.8	5.6	3.2	1.5	0	0.7	0.6	4.2	3.0	1.0
130	425	1.4	0.7	0.1	0.7	0.7	0.1	0	0.7	1.2	4.7	2.7	0.7
137	450				1.3	0.8	0.3				3.2	1.8	0.6
145	475				1.2	0.6	0.2				2.4	2.0	0.4
152	500				2.8	1.7	0.7				2.3	1.7	1.1
160	525				1.1	0.5	0.1				3.2	2.0	0.8
168	550										5.0	2.6	0.7
175	575										0	0.1	0.2
183	600										1.0	0.7	0.7
191	625										2.2	1.3	0.7
198	650										2.2	1.4	0.3
206	675										0.4	0.3	0.4
213	700										0.4	0.2	0.1
221	725										0	0	0.2

NOTE: Explosive charges were positioned in the center of the magazines. Angular deviations are half angles.

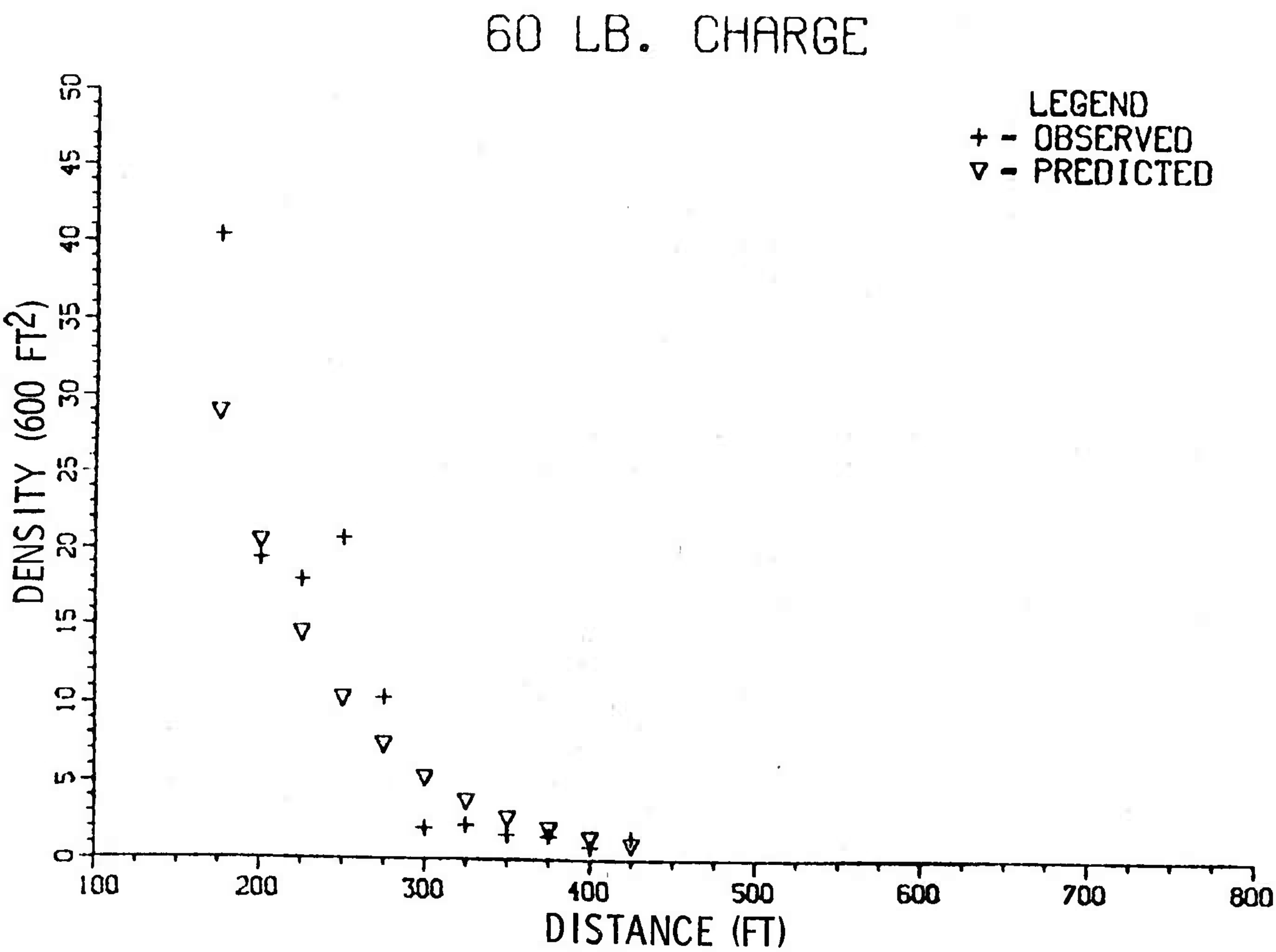

Figure 16. Hazardous Fragment Densities (600 ft^2) Versus Distance in Front of an Igloo Magazine-27Kg TNT Charge Positioned in the Center of Igloo Statically Detonated

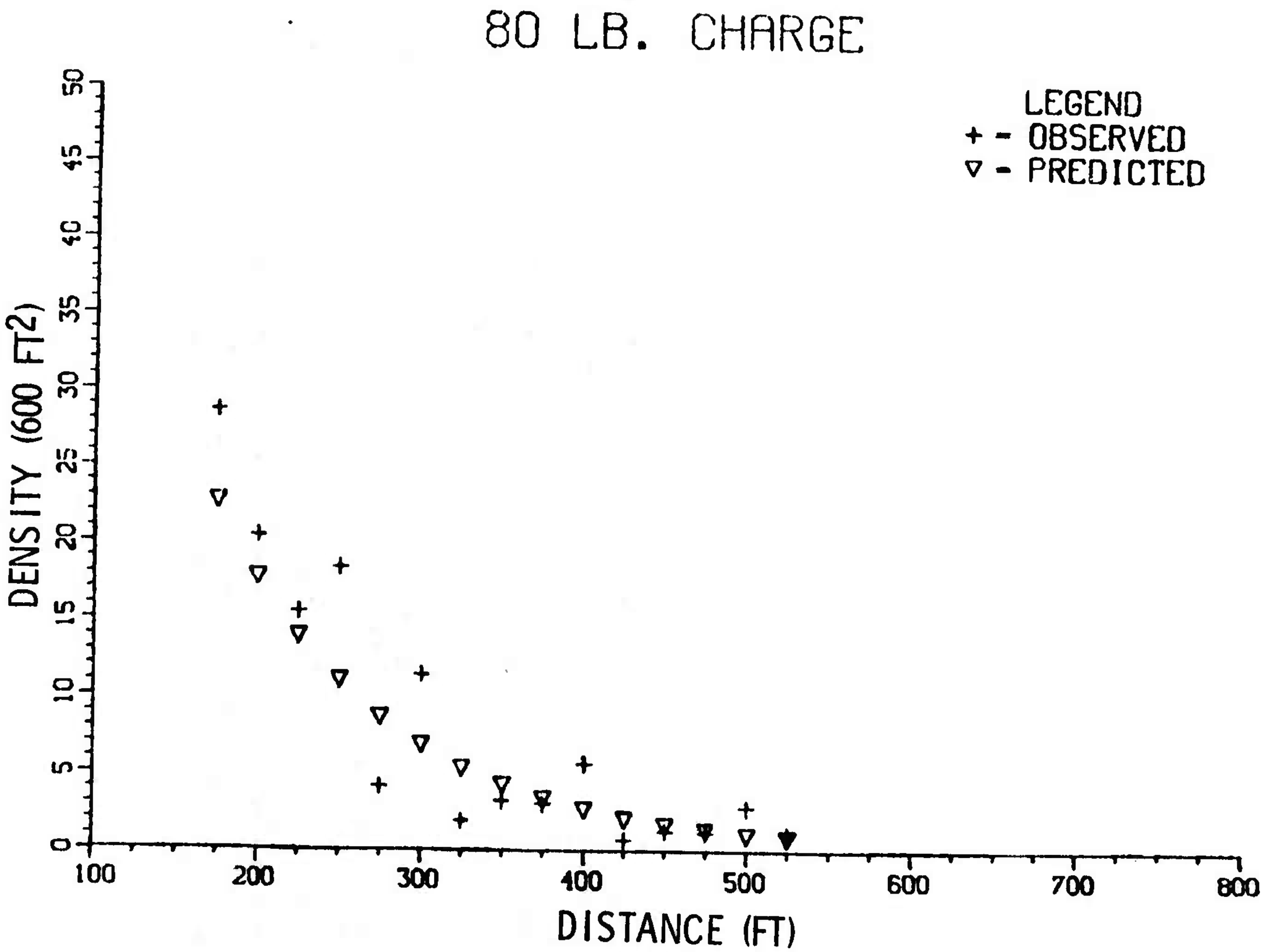

Figure 17. Hazardous Fragment (600 ft^2) Versus Distance in Front of an Igloo Magazine-36Kg TNT Charge Positioned in the Center of the Igloo Statically Detonated

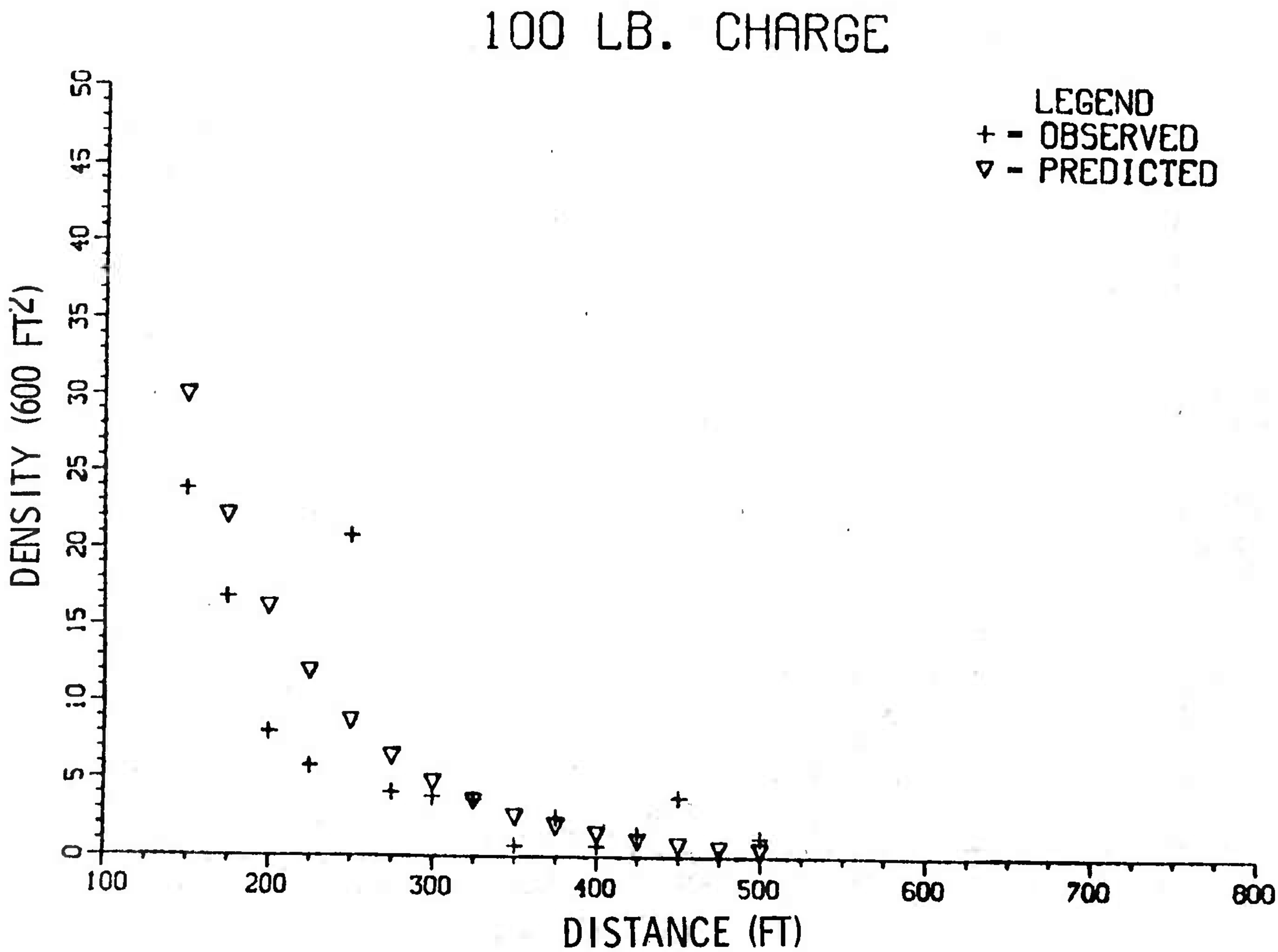

Figure 18. Hazardous Fragment Densities (600 ft^2) Versus Distance in Front of an Igloo Magazine-45 Kg TNT Charge Positioned in the Center of Igloo Statically Detonated

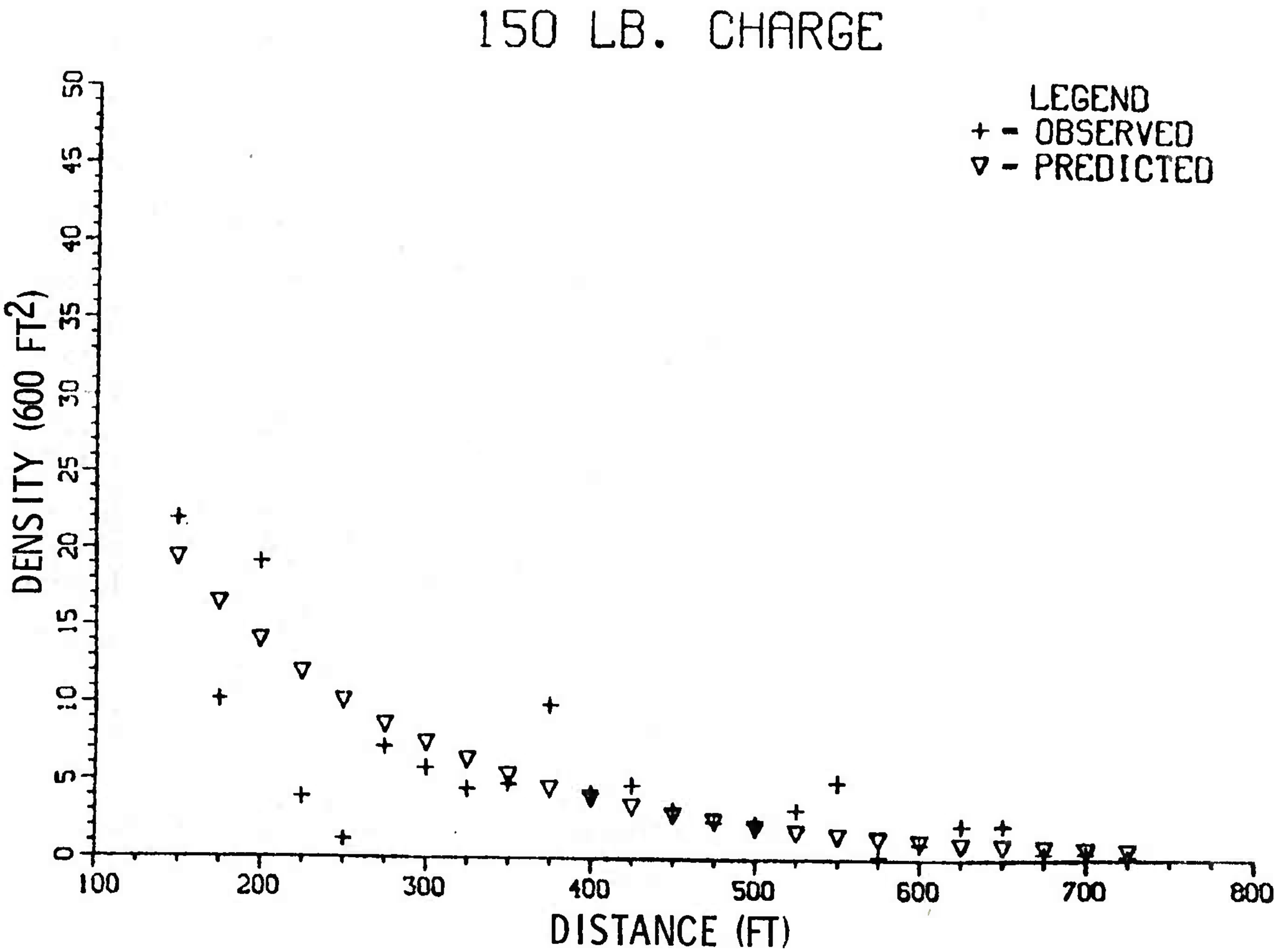

Figure 19. Hazardous Fragment Densities (600 ft^2) Versus Distance in Front of an Igloo Magazine-68 Kg TNT Charge Positioned in the Center of Igloo Statically Detonated

Table 4. Estimates of Initial Door Velocities and Times of Arrival of the Reflected Shock Waves

Charge	Initial Door Velocity (mps)	Times of Arrival (m sec)
5.4 Kg - 4 metres from the headwall	28	145
5.4 Kg - 20.4 metres from the headwall	41	81
7.3 Kg - 4 metres from the headwall	29	132
10.9 Kg - 4 metres from the headwall	50	131
45.4 Kg - 12 metres from the headwall	91	Not observed

assumed that the doors could have traveled up to 150 metres in front of the magazines, at explosive charge weights of only 5.4 Kg, if the blast shields were not in place. The hazards associated with door separation, at low explosive charge weights, could be eliminated by employing fully vented doors, e.g., stretch chain link fencing fabric over metal door frames.

Variations in the structural response of the magazines, at HE charge weights up to 18 Kg, were not significant in terms of establishing hazardous fragment* distances, i.e., the maximum distance at which the hazardous fragment density is at least one per 600 ft^2. The sidewalls and arch crest of the magazine either remained standing or fell to the floor, at these low charge weights. The sidewalls were blown out and recovered in large pieces off the sides of the magazines. The headwalls tended to break up into smaller pieces as the charge weight increased with more and more of them being projected over the blast shield and to the sides of the magazines. An apparent reversal in this trend can be found in Table 3, where the hazardous fragment densities for the 36 Kg test were greater than those for the 45 Kg test. However, an examination of the individual fragment recovery data for these two tests show that more fragments were recovered outside the 45 degree recovery zone in the 45 Kg test than in the 36 Kg test.

The maximum distance at which the hazardous fragment density exceeded one per 600 ft^2, in these tests, was greater than that observed in the Navajo tests at identical explosive charge weights (68 Kg). These differences are assumed to be real and the result of a different door and headwall design. The presence of the blast shield did not affect maximum hazardous fragment distances. Those fragments that travelled the farthest came from the top of the headwall and were projected over the top of the blast shield. However, the blast shield did stop many fragments; and had it not been in place the density close in would have been much greater. Fragment hazards to the front of the magazines could have been eliminated in this series of tests if the blast shields had been higher. Unfortunately, employing higher blast shields to control fragment hazards in front of the magazines, at small HE charge weights, would increase hazardous fragment densities to the sides of the magazines.

If the headwalls and doors were replaced with chain link fencing fabric, full venting would occur; and fragments would not be produced by these currently used structures. In this case, thousands of pounds of explosives would be required to produce overpressures to the front or fragment hazards to the sides and rear of the magazine, which are unacceptable. Primary fragments from any ordnance items stored in the magazines could be controlled via sandbag barrier walls.

The non-hazardous overpressures measured off the side of the headwall in this series of tests, with an HE charge weight of 68 Kg, were slightly higher than those observed in the Navajo tests (8.5kPA at 27.4 metres versus 3.4kPA at 24.4 metres) at the same charge weight. The increase can be attributed to the presence of the blast shield in the Hastings test, the relatively heavy

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**Any fragment weighing at least 0.18 Kg (0.4 lb) is assumed to be hazardous.*

steel doors on the Navajo magazines, and variations in the design of the headwalls.

V. CONCLUSIONS AND RECOMMENDATIONS

The maximum distance requirement between inhabited buildings and standard-size, earth-covered igloo magazines containing small explosive charge weights will be determined by door displacement and not by concrete fragments from the headwall. Blast shields will reduce this distance and change the direction of the hazard from the front to the sides, at small charge weights.

Blast shields are effective in controlling concrete fragment hazards from the headwalls at explosive charge weights up to 18 Kg. At higher explosive charge weights, significant numbers of fragments will be projected over the blast shield.

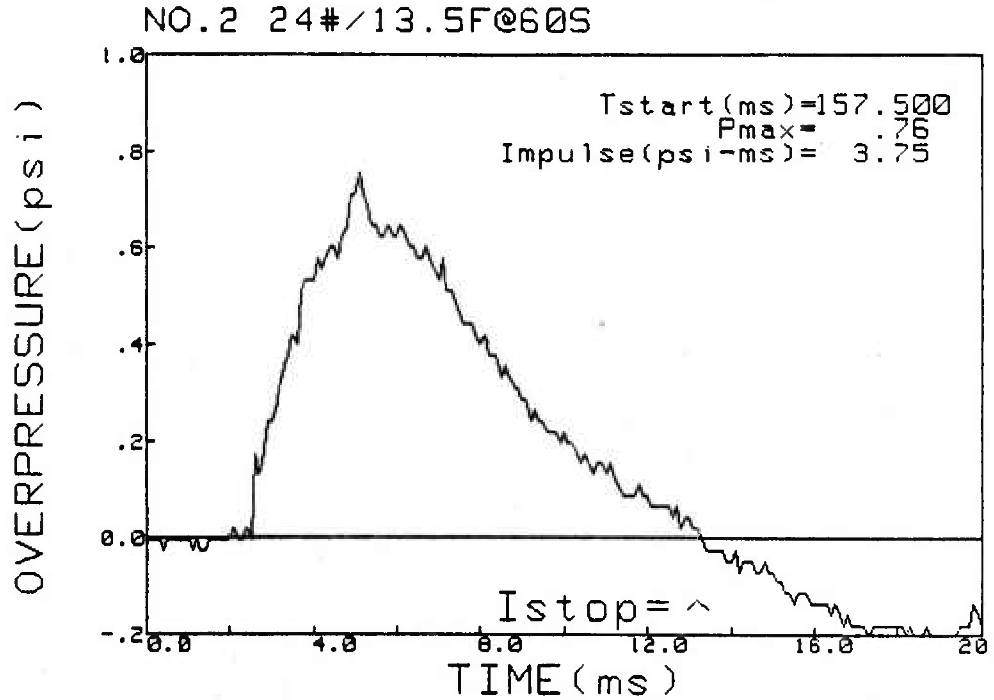
Igloo magazines will suffer severe structural damage when explosive charges as small as 5.4 Kg TNT detonate inside a magazine. Explosive charge weights of 7.3 Kg can completely destroy a magazine.

There are no significant overpressure hazards, outside of a magazine, associated with the detonation of up to 68 Kg TNT inside a magazine.

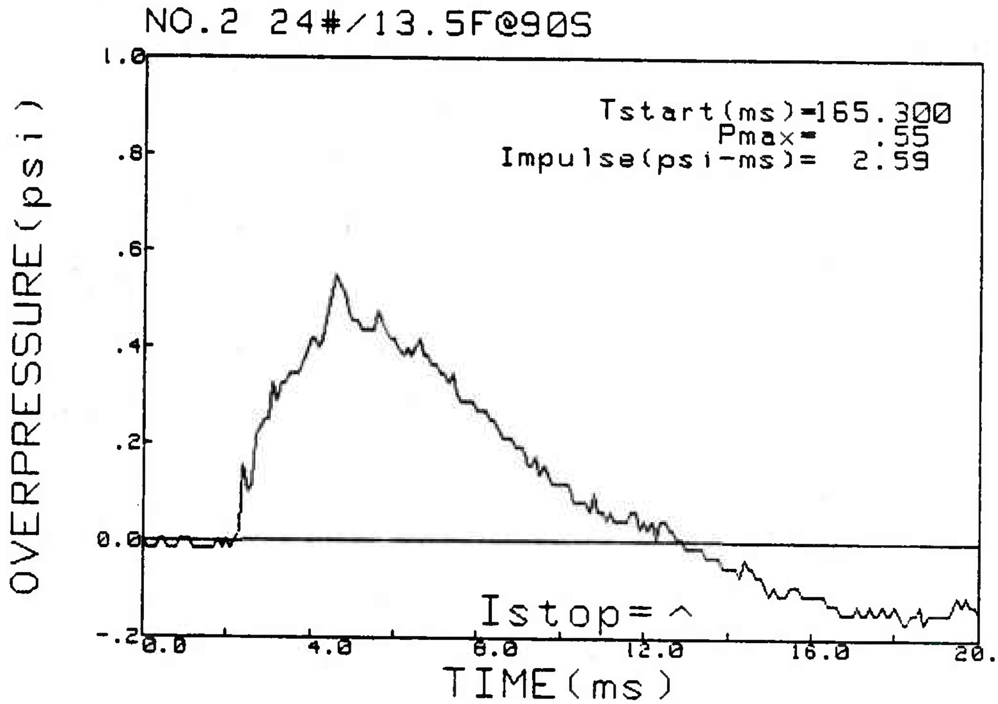
Tests should be conducted to determine overpressure and fragment hazards when explosive charges are detonated inside igloo magazines with fully vented non-fragment producing headwalls and doors.

APPENDIX A

External Pressure Time Histories From Explosive Charges Positioned Inside Earth Covered Igloo Magazines

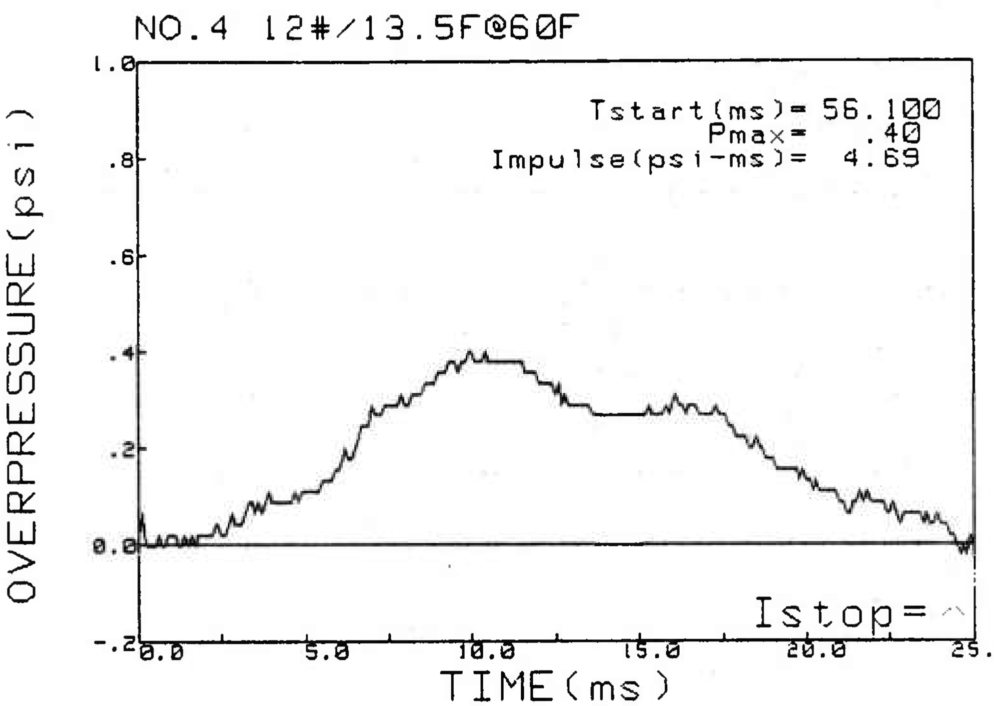


Gage positioned 18.3 m off the side of the headwall



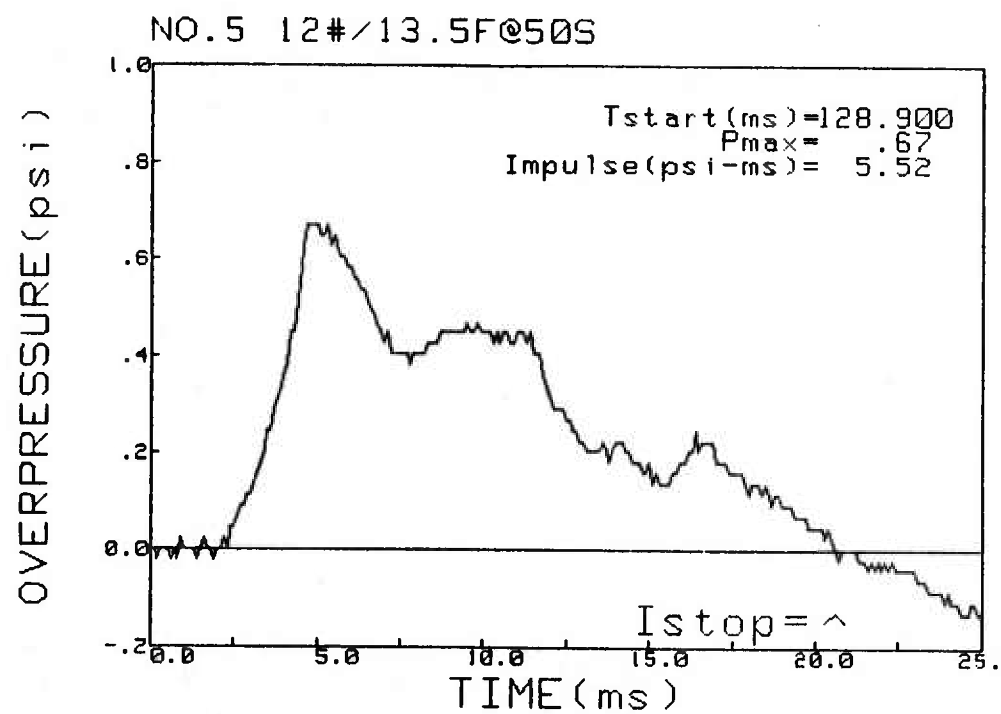
Gage positioned 27.4 m off the side of the headwall

Figure A-1. Pressure Time Histories, Test No. 2, 12.9 Kg TNT Charge Positioned 4 Metres from Headwall

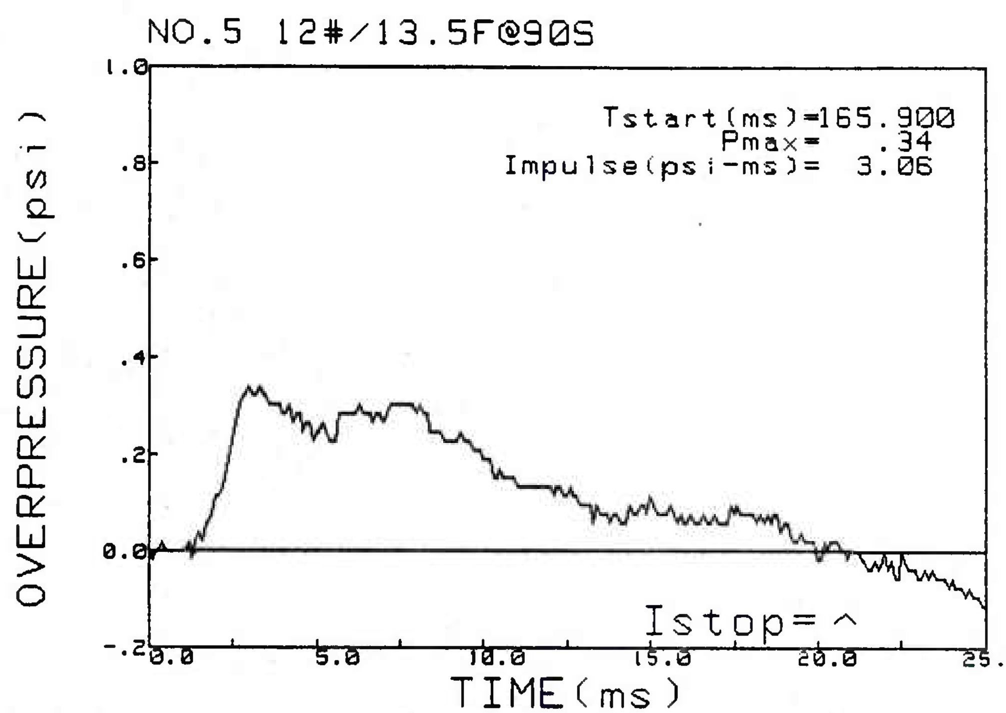


Gage positioned 18.3 m in front of the headwall

Figure A-2. Pressure Time History, Test No. 4, 5.4 Kg TNT Charge Positioned 4 Metres from Headwall

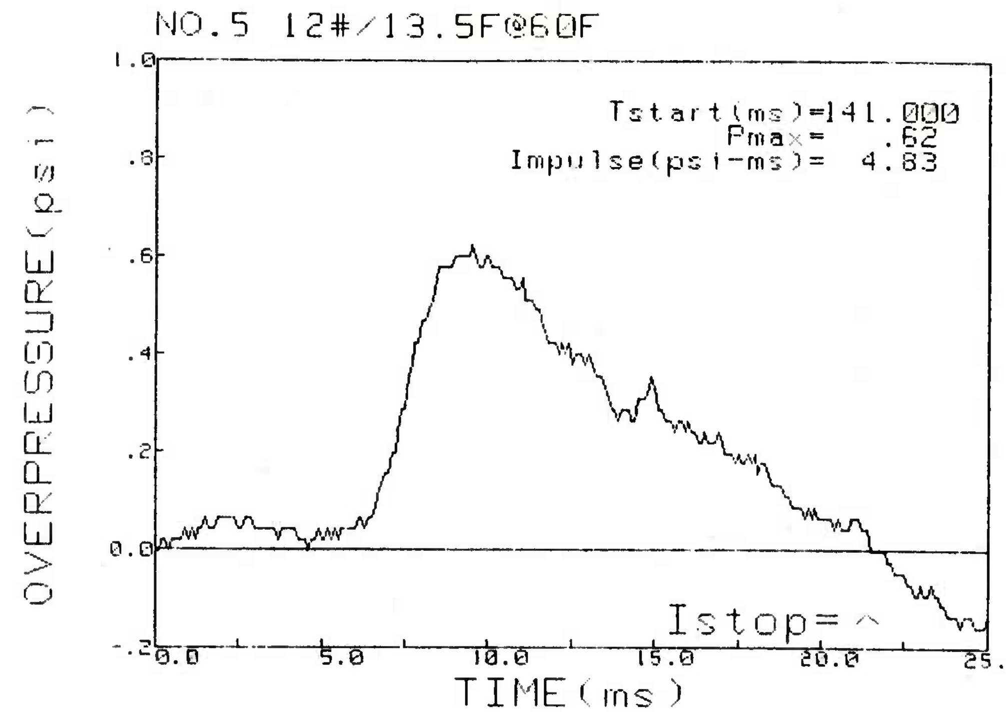


Gage positioned 15.2 m off the side of the headwall

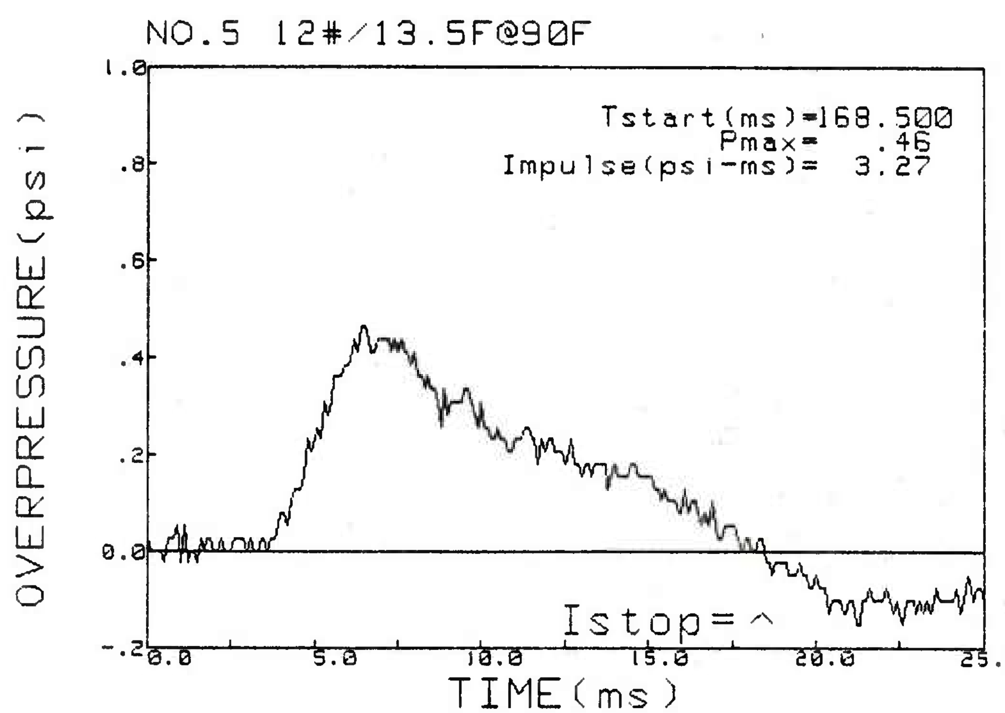


Gage positioned 27.4 m off the side of the headwall

Figure A-3. Pressure Time Histories, Test No. 5, 5.4 Kg TNT Charge Positioned 4 Metres from Headwall

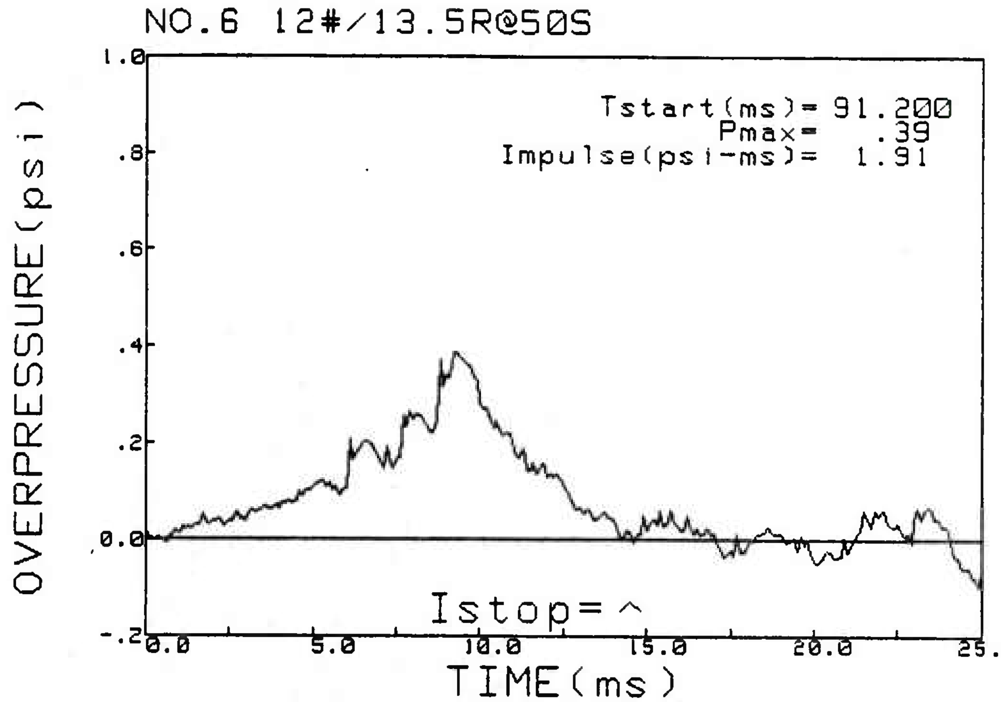


Gage positioned 18.3 m in front of the headwall

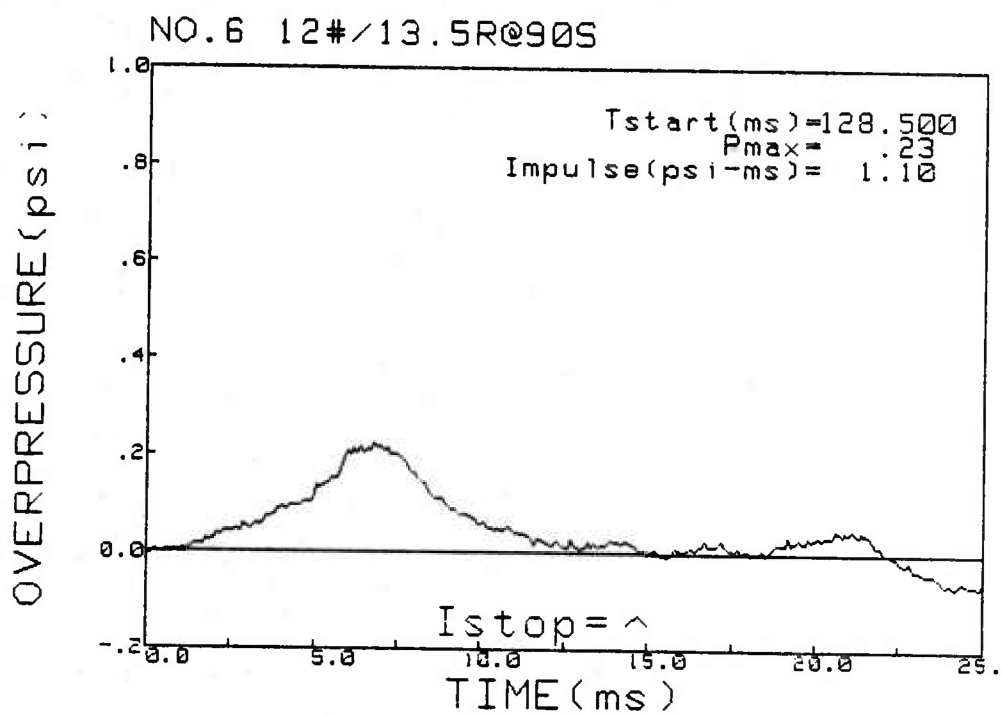


Gage positioned 27.4 m in front of the headwall

Figure A-4. Pressure Time Histories, Test No. 5, 5.4 Kg TNT Charge Positioned 4 Metres from Headwall

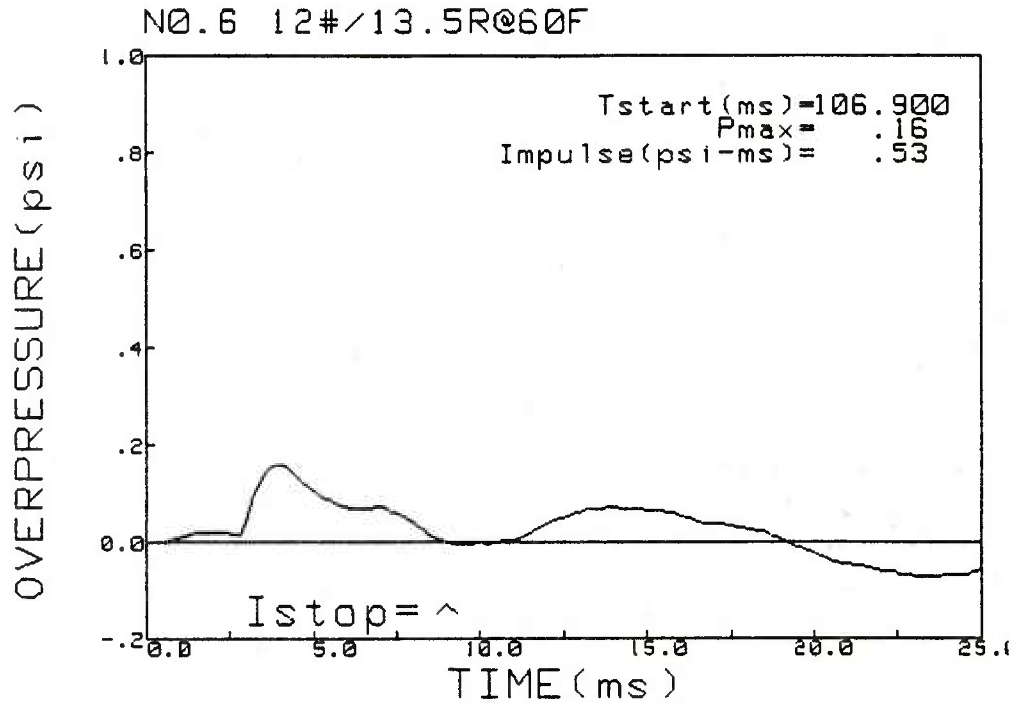


Gage positioned 15.2 m off the side of the headwall

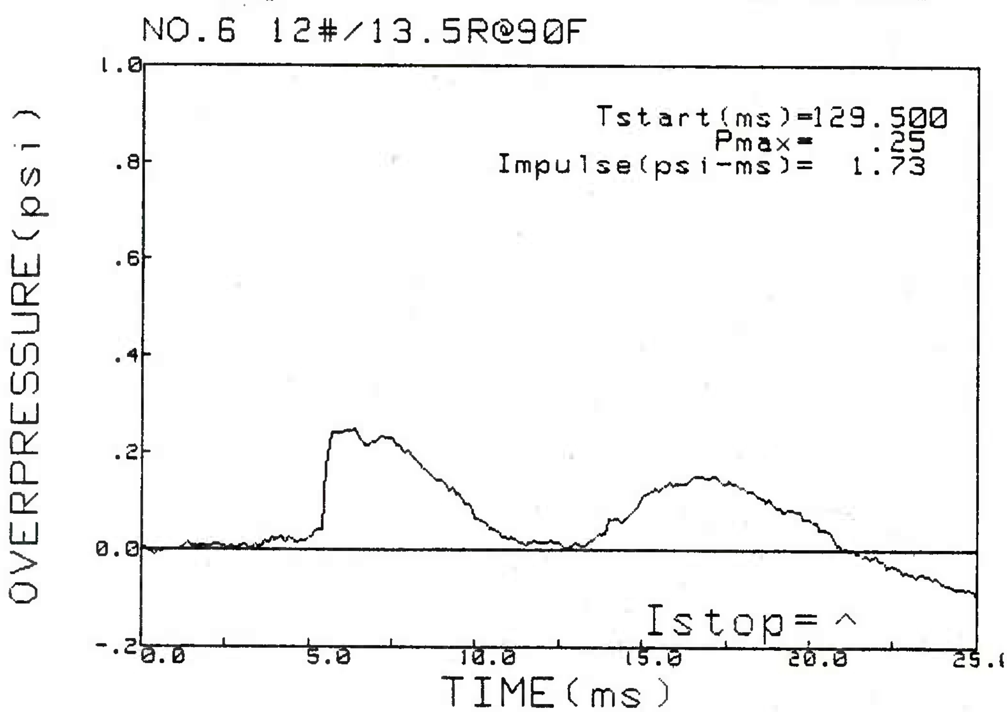


Gage positioned 27.4 m off the side of the headwall

Figure A-5. Pressure Time Histories, Test No. 6, 5.4 Kg TNT Charge Positioned 20.4 Metres from Headwall

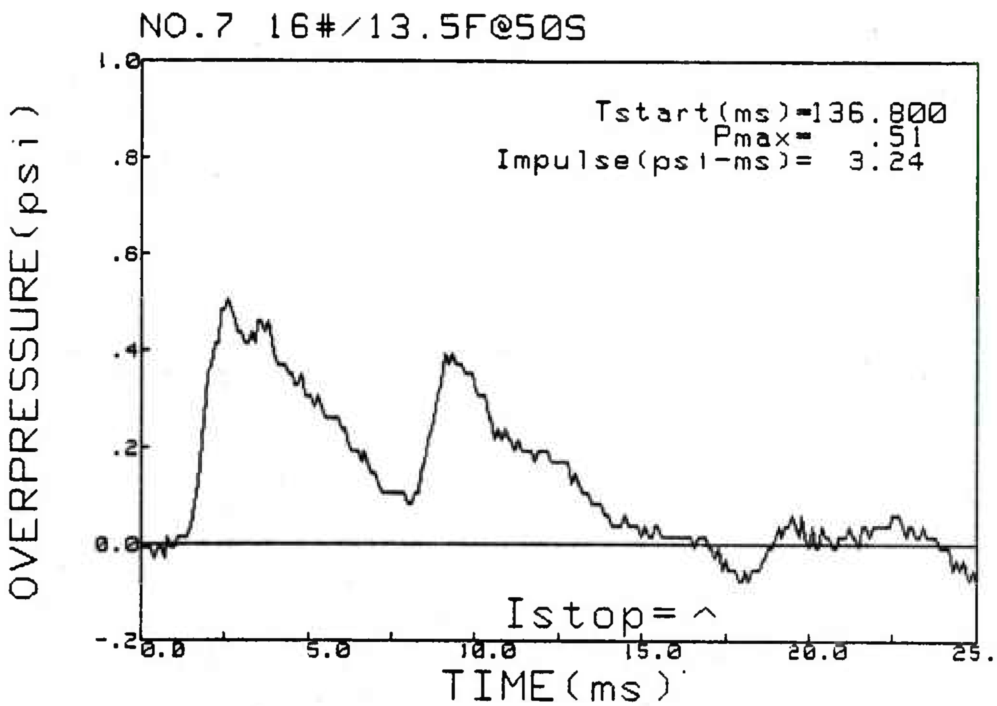


Gage positioned 18.3 m in front of the headwall

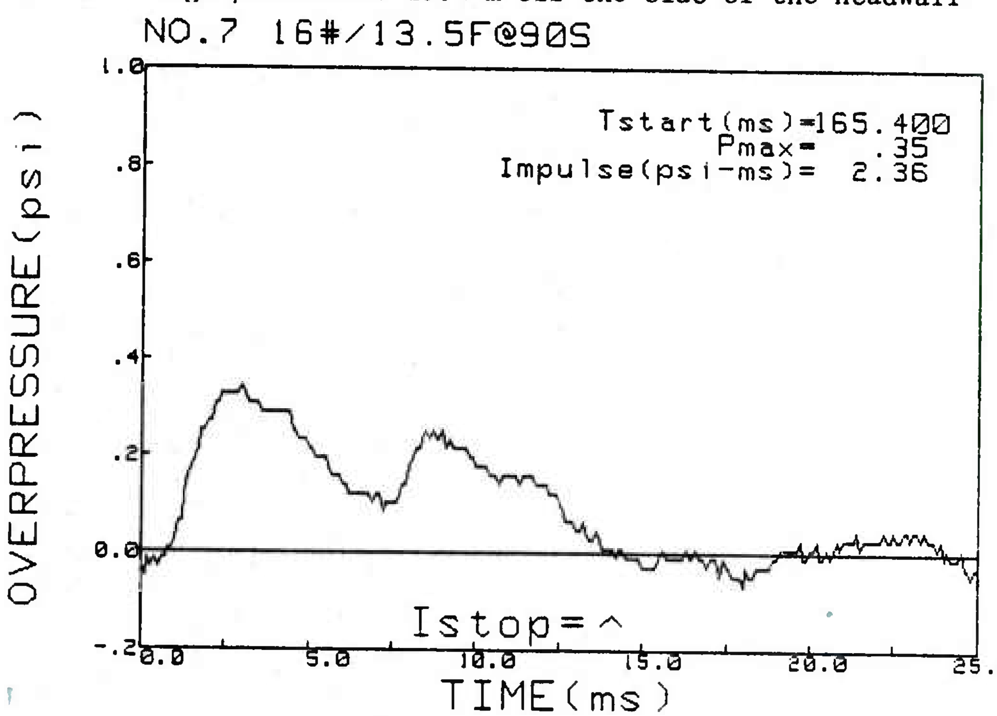


Gage positioned 27.4 m in front of the headwall

Figure A-6. Pressure Time Histories, Test No. 5, 5.4 Kg TNT Charge Positioned 20.4 Metres from Headwall

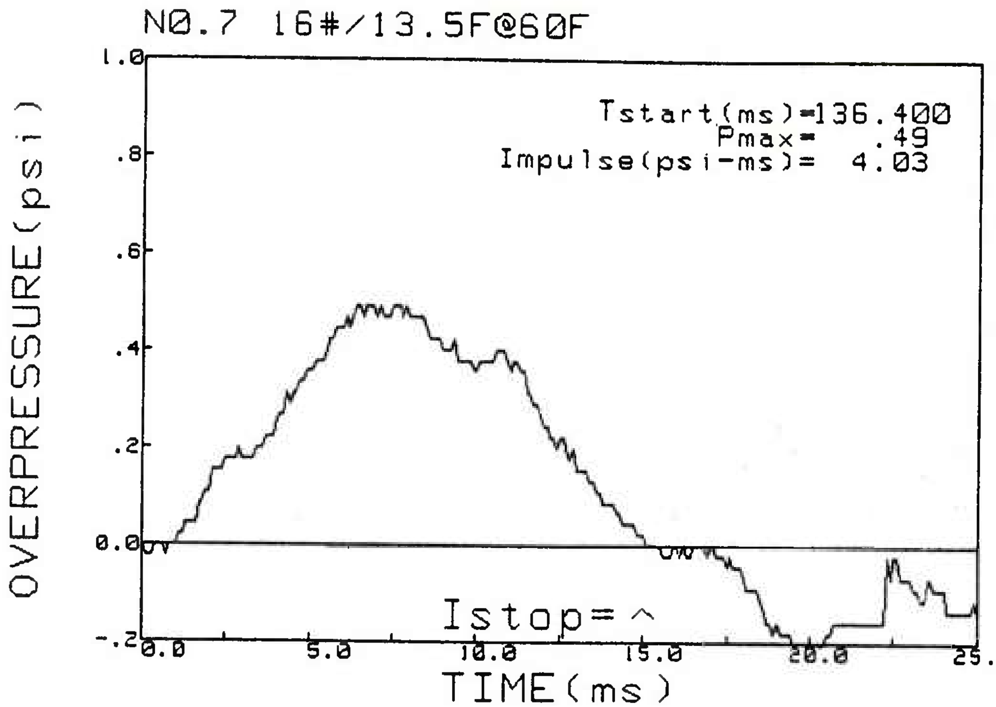


Gage positioned 15.2 m off the side of the headwall

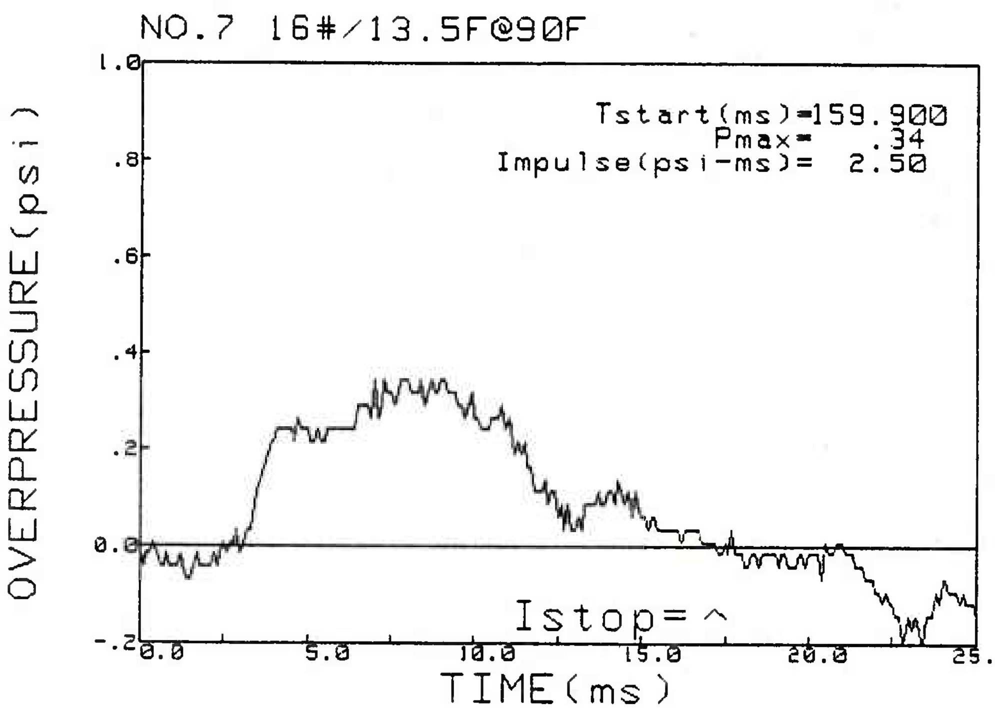


Gage positioned 27.4 m off the side of the headwall

Figure A-7. Pressure Time Histories, Test No. 7, 7.3 Kg TNT Charge Positioned 4 Metres from Headwall

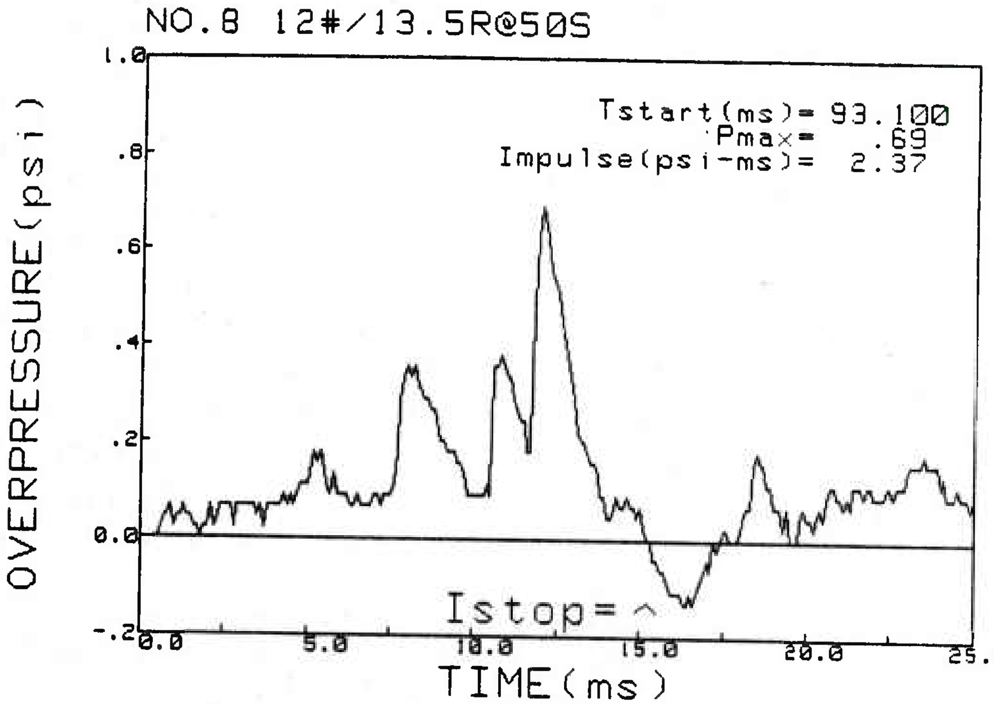


Gage positioned 18.3 m in front of the headwall

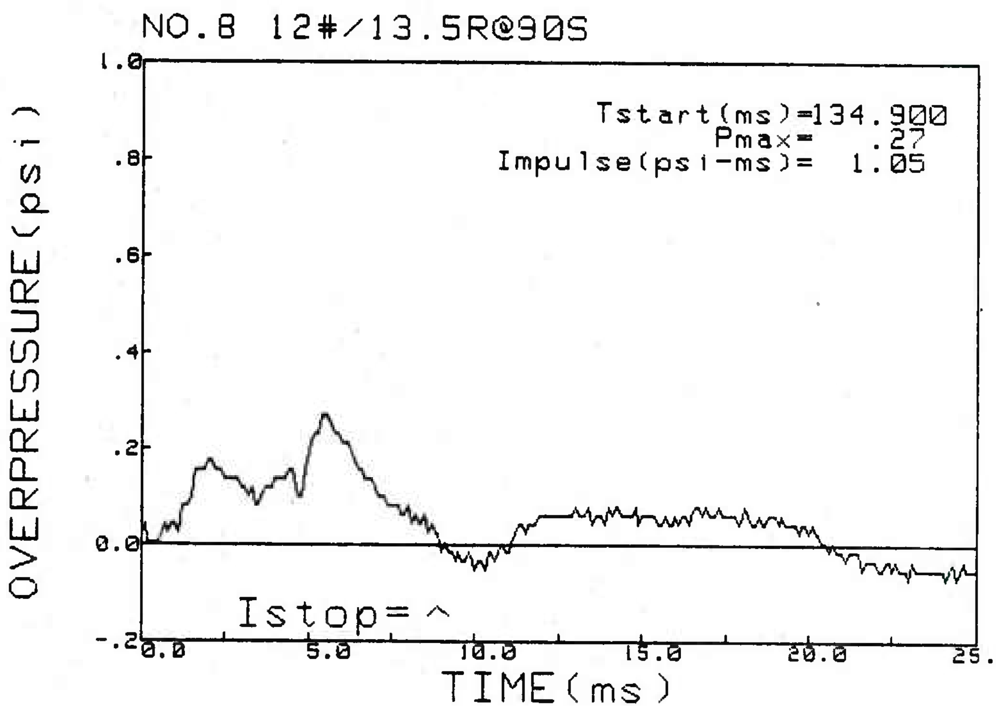


Gage positioned 27.4 m in front of the headwall

Figure A-8. Pressure Time Histories, Test No. 7, 7.3 Kg TNT Charge Positioned 4 Metres from Headwall

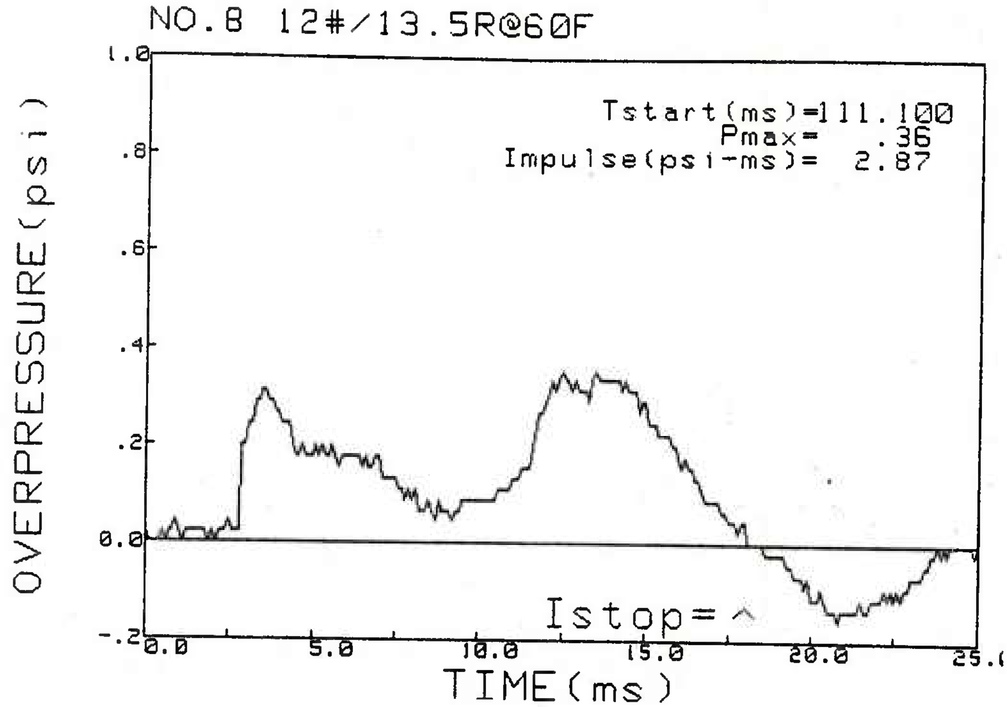


Gage positioned 15.2 m off the side of the headwall

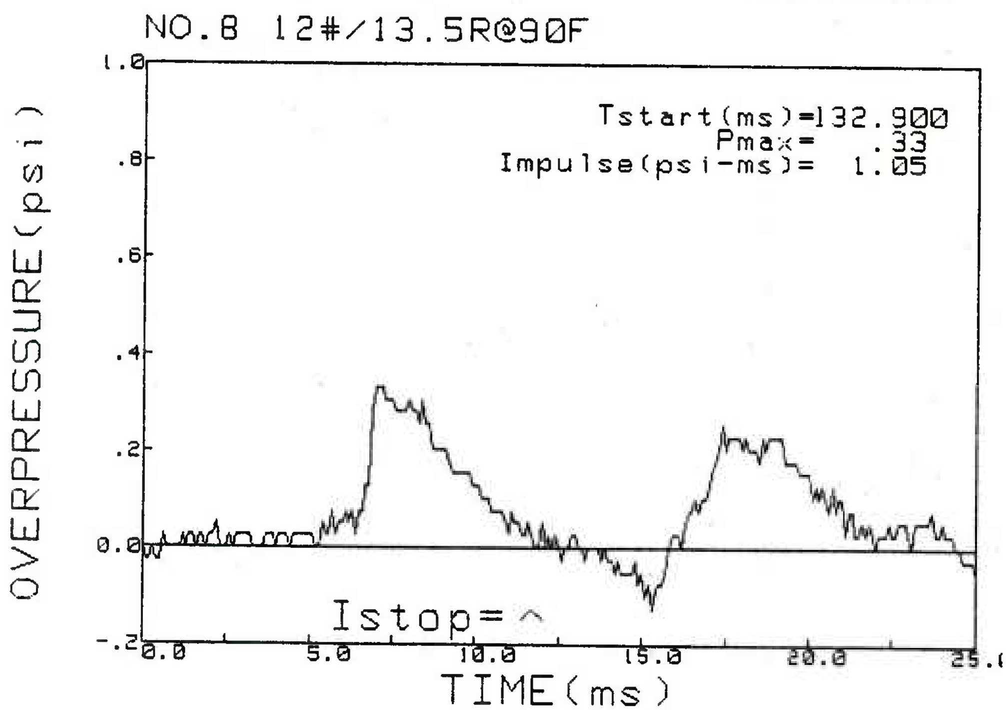


Gage positioned 27.4 m off the side of the headwall

Figure A-9. Pressure Time Histories, Test No. 8, 5.4 Kg TNT Charge Positioned 20.4 Metres from Headwall

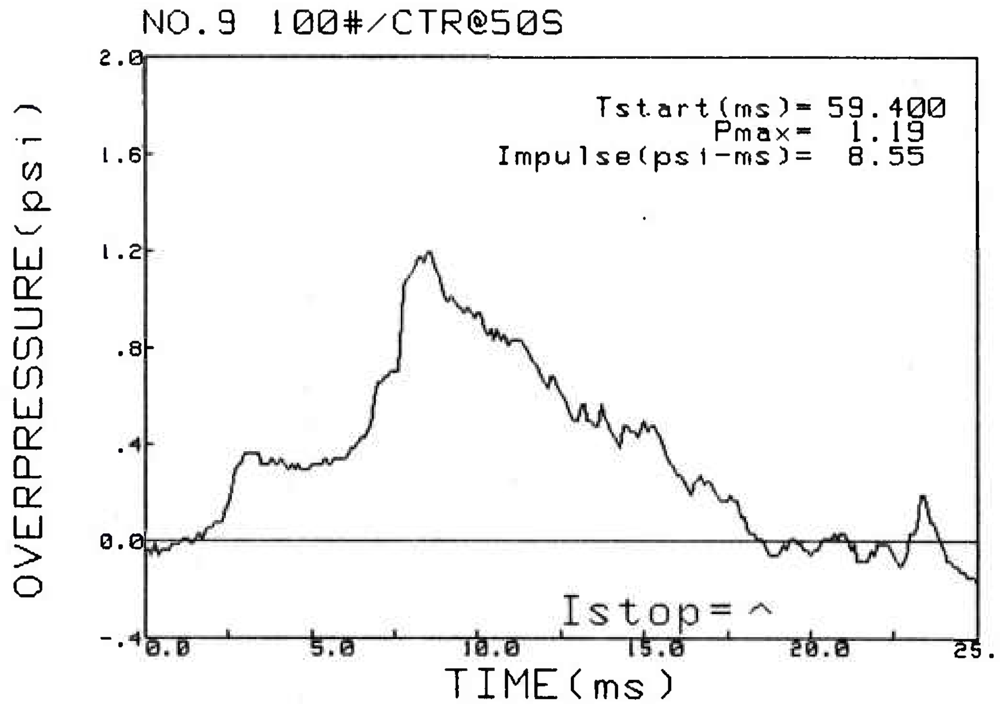


Gage positioned 18.3 m in front of the headwall

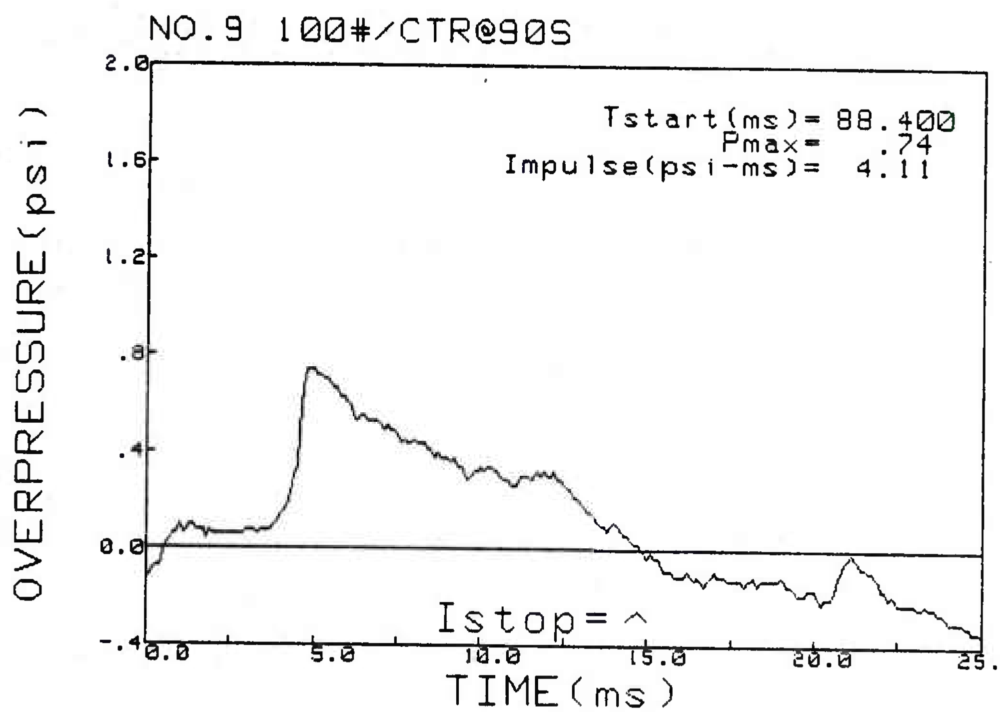


Gage positioned 27.4 m in front of the headwall

Figure A-10. Pressure Time Histories, Test No. 8, 5.4 Kg TNT Charge Positioned 20.4 Metres from Headwall

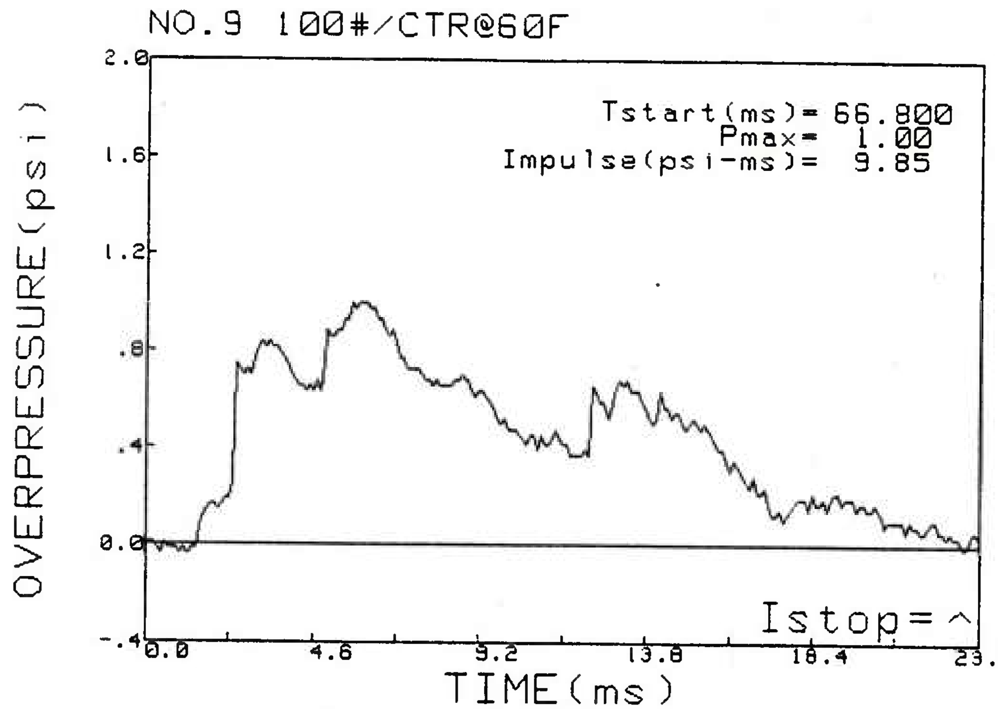


Gage positioned 15.2 m off the side of the headwall

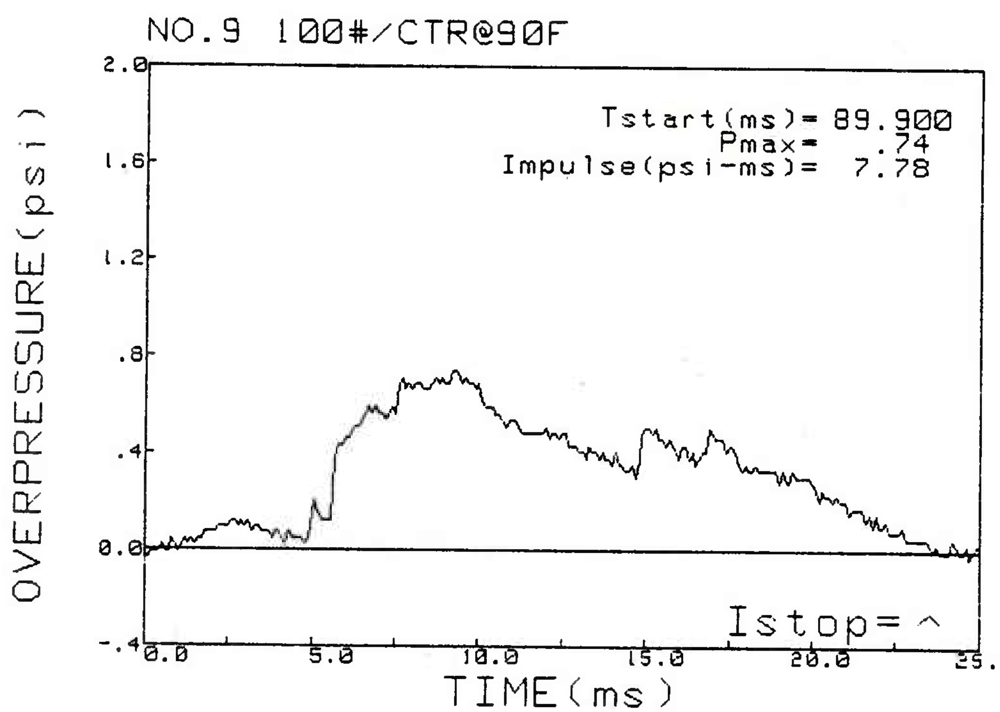


Gage positioned 27.4 m off the side of the headwall

Figure A-11. Pressure Time Histories, Test No. 9, 45.4 Kg TNT Charge Positioned 12 Metres from Headwall

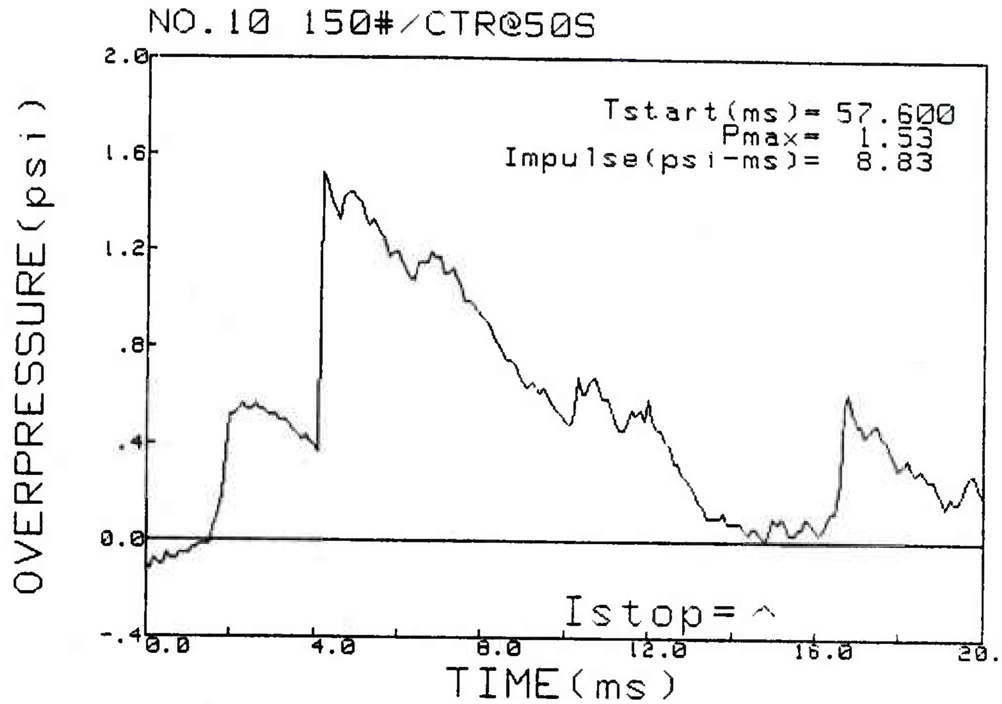


Gage positioned 18.3 m in front of the headwall

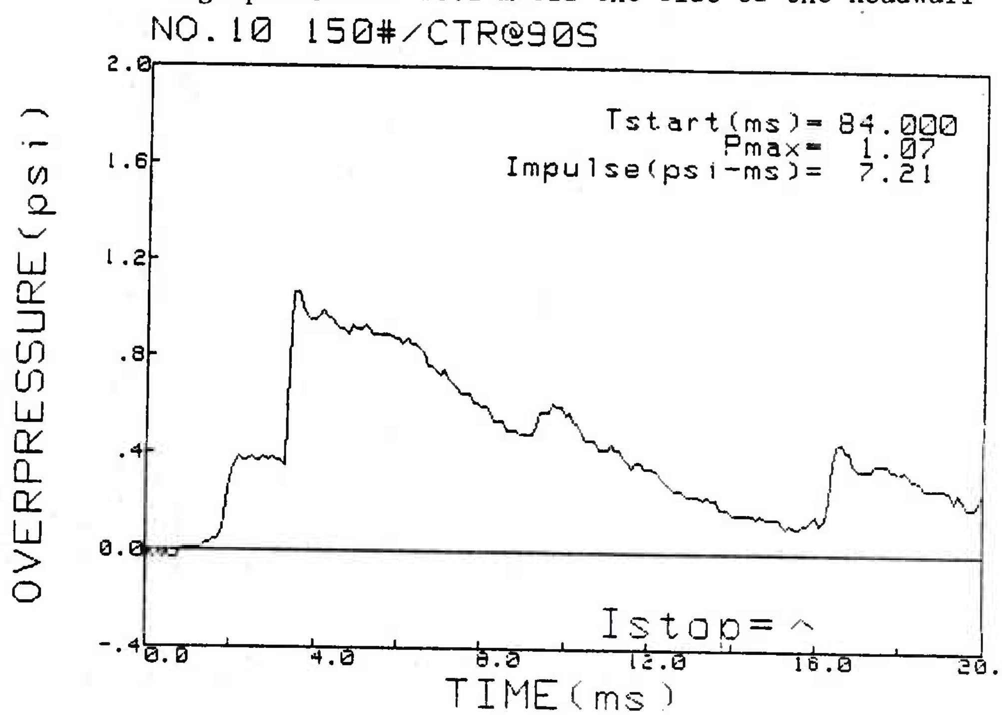


Gage positioned 27.4 m in front of the headwall

Figure A-12. Pressure Time Histories, Test No. 9, 45.4 Kg TNT Charge Positioned 12 Metres from Headwall

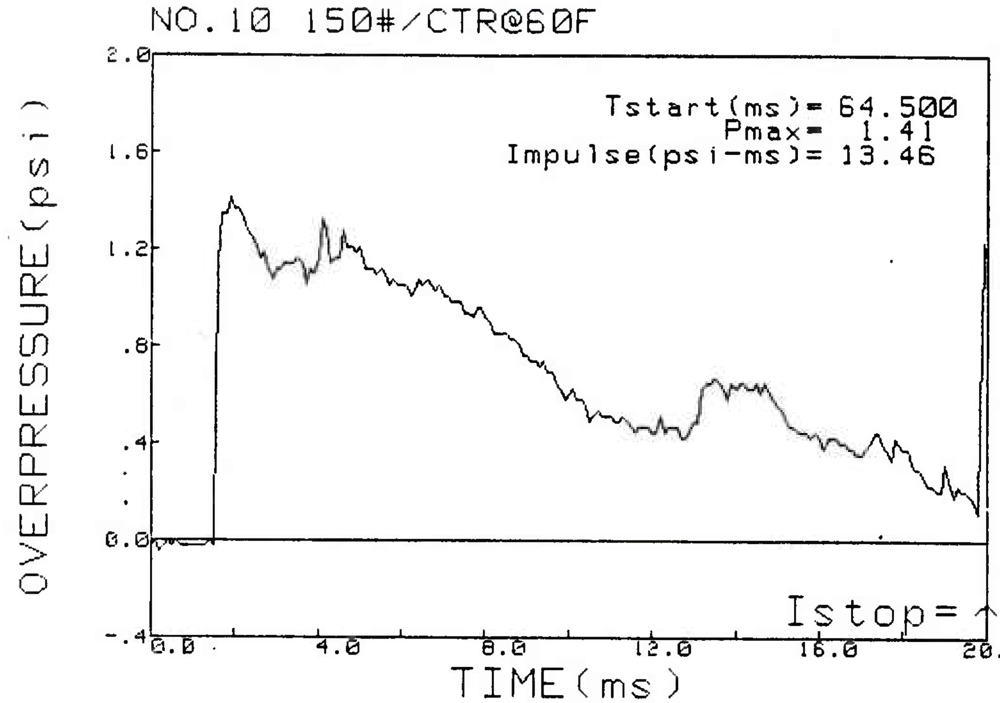


Gage positioned 15.2 m off the side of the headwall

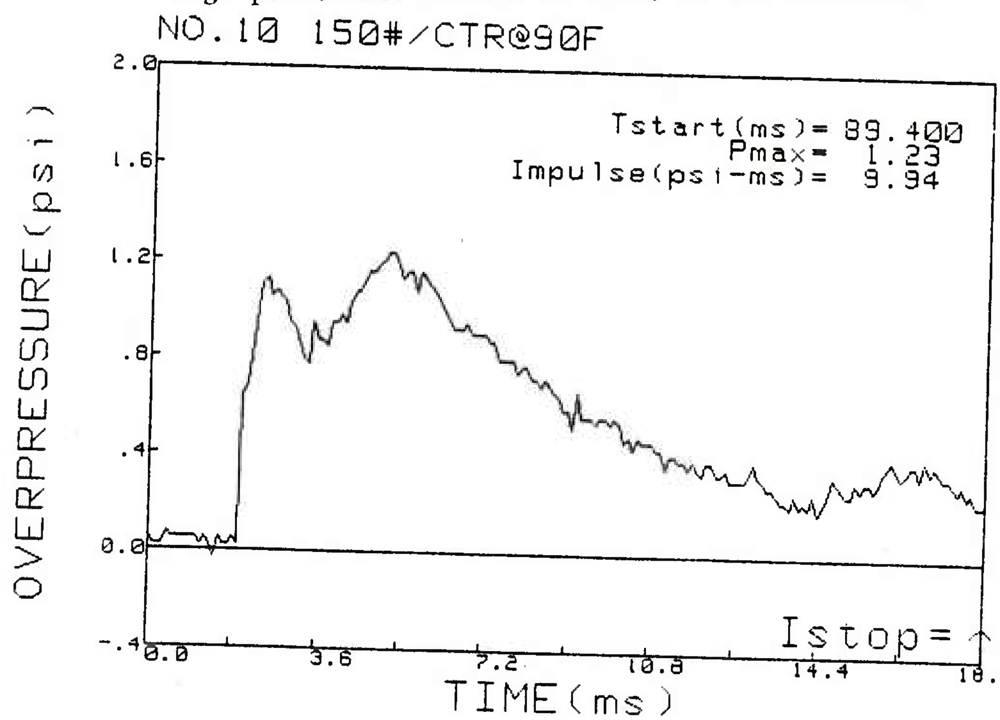


Gage positioned 27.4 m off the side of the headwall

Figure A-13. Pressure Time Histories, Test No. 10, 68 Kg TNT Charge Positioned 12 Metres from Headwall



Gage positioned 18.3 m in front of the headwall



Gage positioned 27.4 m in front of the headwall

Figure A-14. Pressure Time Histories, Test No. 10, 68 Kg TNT Charge Positioned 12 Metres from Headwall

APPENDIX B

Individual Fragment Recovery Data

APPENDIX B

Individual Fragment Recovery Data

Coded Data Format Instructions

First entry in the three letter code is the HE charge weight:

A = 27 Kg, B = 36 Kg, C = 45 Kg, D = 68 Kg

Second entry is the weight group in pounds:

E = 0.4-1.0, F = 1-5, G = 5-10, H = 10-50, I = 50+

Third entry denotes recovery area:

L = Left side recovery area, R = Right side recovery area

First column entry is the distance (ft.) to the front or behind the head-wall, if preceded by a - sign, where the fragment came to rest.

Second column entry is the deviation (ft.) to either the right side or the left side, from the centerline, where the fragment came to rest.

A	E L
0	55
30	65
30	65
30	65
30	65
10	50
40	70
65	20
65	20
65	20
70	20
70	20
70	20
80	5
80	5
80	5
80	25
95	5
110	20
110	25
115	10
130	5
130	5
125	30
135	5
135	30
140	5
140	10
145	15
195	10
200	5
200	5
205	5
215	35
220	10
250	40
260	5
275	5
270	60
200	60
200	60
140	75
100	60

AEL	
0	180
120	130

A	F L
-10	70
0	60
10	75
10	60
20	75
15	100
25	65
20	75
20	75
10	50
40	65
50	70
50	60
50	95
50	80
60	0
70	70
70	65
65	5
65	15
65	20
70	20
70	20
70	15
70	20
70	25
80	20
75	25
75	25
75	20
90	10
100	30
95	0
105	0
110	5
115	10
125	30
120	25
125	10
130	5

AFL	
125	25
125	25
125	25
125	25
125	25
130	5
135	35
135	15
140	5
135	30
130	25
130	25
145	40
140	10
140	25
150	20
150	15
155	20
150	30
170	5
170	15
180	20
180	25
180	25
190	25
190	20
190	25
190	35
195	35
200	25
205	5
205	10
210	10
230	5
250	25
260	15
260	25
275	50
275	45
310	5
350	15
340	90
340	100
300	75
275	55

AFL	
230	90
175	75
170	90
160	55
140	60
120	90
10	150
20	125
20	140
30	180
30	130
55	140
60	125
75	160
75	190
90	140
140	140
150	150
150	150
160	150
280	195

A	G L
20	65
60	15
60	20
70	35
85	15
70	15
70	15
85	5
80	20

A	H L
60	65
65	60
65	20
95	35
250	100
230	90
95	25
135	10
135	5

AHL	
135	5
320	20
175	65
135	25
155	5
170	45
170	15
105	65
100	55
130	15
185	35
205	25
255	40
0	180
10	250
-80	275

A	I L
-10	70
-5	90
60	95

A	E R
15	100
15	50
15	70
200	10
30	65
55	50
65	20
220	15
70	10
90	5
110	15
235	25
185	5
195	10
205	20
250	25

A	F R
0	60

Table B-1 Individual Fragment Recovery Data

AFL

0	90
20	55
40	70
20	60
25	70
35	50
50	70
40	100
240	40
45	50
55	50
65	75
65	75
60	10
60	20
65	10
70	30
70	5
250	100
70	10
75	5
80	5
100	20
105	5
105	10
125	15
120	55
135	5
250	20
130	10
135	0
150	5
160	0
170	50
170	60
190	15
190	5
240	40
265	25
360	85

A G R

50	70
125	25

AGR

150	5
300	5

A H R

230	0
340	90

B E L

60	40
70	35
70	40
100	5
120	5
120	20
135	5
135	5
175	25
175	25
190	40
375	25
425	25
310	100
300	100
295	55
285	60
285	60
280	100
50	90
40	70
250	145
250	175
250	150
325	125
400	150
270	260
200	200
70	240

B F L

65	35
70	60
65	40

BFL

70	35
70	30
80	20
90	20
95	15
100	5
115	20
120	20
130	5
135	35
140	5
140	5
145	20
150	0
150	0
145	30
150	20
150	25
150	15
155	25
160	0
170	30
175	25
175	30
175	25
180	25
180	5
180	20
180	20
190	20
190	0
190	40
190	5
205	20
205	10
205	10
210	15
215	20
250	25
255	30
255	25
260	5
280	30
280	10
290	20

BFL

330	25
340	20
365	40
450	90
450	90
350	90
340	55
290	100
280	100
225	55
230	50
240	100
190	65
140	90
80	75
50	50
50	60
50	70
40	80
35	60
45	55
45	70
40	70
45	55
80	160
210	165
205	145
300	125
290	110
300	170
300	110
340	125
400	150
400	150
275	260

B G L

135	5
140	5
140	5
145	15
175	0
200	0
240	25

BGL

250	0
295	5
300	0
430	100
300	80
35	60
35	60
15	60
350	125
20	240

B H L

140	20
190	25
340	25
345	20
285	100
70	160
10	250

B E R

10	70
20	65
65	75
50	95
100	30
100	30
130	0
130	0
130	5
160	40
160	5
170	10
180	0
175	20
210	15
220	25
220	25
235	5
245	5
245	5
260	70
290	60

Table B-1 Individual Fragment Recovery Data (continued)

BER	
295	75
300	75
330	15
330	100
360	75
440	75
440	20
440	20

B F R	
5	65
10	100
30	65
55	70
55	65
60	70
60	75
55	60
65	75
100	15
100	15
100	15
100	15
100	20
100	0
110	20
110	20
110	20
110	20
120	0
120	20
120	20
120	20
120	5
125	0
125	5
130	10
130	10
135	0
135	0
130	5
140	5
140	5
140	30

BFR	
140	100
140	50
140	30
145	5
150	10
160	30
160	30
170	10
170	10
170	10
180	40
180	5
190	5
200	30
200	20
210	15
220	25
210	15
210	0
225	15
230	35
230	20
240	5
240	5
245	10
250	30
250	20
250	5
260	30
260	5
270	45
270	50
275	45
290	30
300	30
295	70
300	70
300	75
300	90
330	30
330	15
330	5
340	30
360	20
360	20

BFR	
375	80
390	25
390	15
390	85
415	20
450	40
440	20
445	20
470	30

B G R	
10	95
110	5
110	10
140	30
180	10
185	5
250	20
280	60
360	20
360	70
390	70
445	60
470	40

B H R	
190	0
195	25
200	10
210	25
240	50
270	70
335	95

C E L	
45	60
45	60
80	90
80	80
90	15
90	15
90	10

CEL	
90	10
90	15
95	5
95	110
60	110
20	100
15	100
145	15
165	205
300	195
200	230
300	195
300	75
295	65
385	60
380	55
230	25
220	30
210	20
215	50
210	25
210	40
210	30
210	25
210	35
190	15
190	0
180	30
180	30
150	50
130	30
130	25
130	25
125	30
110	30

C F L	
10	95
15	95
10	95
20	95
25	90
25	85
25	80

GFL	
30	100
25	90
25	90
25	90
35	40
45	60
45	60
60	75
70	40
75	45
80	85
95	80
90	15
85	20
85	20
95	5
85	110
70	130
65	115
105	100
20	100
15	100
15	100
0	115
10	140
50	280
90	235
100	375
150	210
140	315
250	250
260	260
300	230
240	205
280	170
300	190
325	190
350	150
320	140
340	125
325	75
270	75
360	60
310	60
320	50

Table B-1 Individual Fragment Recovery Data (continued)

CFL

320	40
360	40
320	40
300	30
390	0
270	45
250	20
250	20
275	40
240	25
230	5
240	40
240	40
230	30
230	45
225	40
210	10
225	40
210	35
205	20
200	40
200	20
200	10
200	5
190	10
190	30
175	35
175	30
175	35
175	30
170	30
165	30
165	30
150	20
150	20
150	20
155	25
160	40
150	40
145	25
145	30
145	30
150	45
140	35
145	40

CFL

140	30
130	10
130	50
130	35
130	0
125	5
120	40
120	25
120	40
125	40
125	40
115	10
105	35
105	5

C G L

25	80
25	80
75	95
60	100
90	235
230	230
400	30
370	30
440	40
400	35
205	25
190	10
180	45
150	30
135	25
120	10
120	25
120	25
120	25
110	10

C H L

20	80
25	80
25	95
215	25
105	30

CHL

90	20
90	20
95	120
200	10
65	125
15	105
300	195
115	25
300	180
280	20
270	20
100	30

C I L

90	100
95	110
0	160
295	60
140	40

C E R

20	90
60	70
65	5
70	10
80	0
85	75
90	90
105	0
125	20
125	50
125	75
140	30
150	0
150	10
150	20
165	5
200	10
200	40
200	50
450	75

C F R

15	95
20	90
20	55
30	60
30	60
30	70
35	80
30	95
35	80
35	75
50	65
60	50
65	5
75	0
80	5
80	15
80	20
100	20
105	0
115	10
160	30
170	0
180	0
190	5
200	30
240	20
270	5
280	5
280	5
300	20
300	15
375	60
385	5
400	15
450	30
450	70
490	90

C G R

5	55
35	100
80	40
85	110

CGR

105	0
165	5
200	10
375	90
-100	5

C H R

30	55
30	70
30	80
85	20
180	30
380	40
-90	0
-100	5

C I R

80	10
240	10
-125	10
-95	10

D E L

220	25
220	25
220	40
220	40
220	40
220	40
230	15
240	10
240	15
230	35
230	35
245	15
245	20
250	20
250	25
240	60
240	60
260	20
250	60

Table B-1 Individual Fragment Recovery Data (continued)

DEL		DEL		DFL		DFL		DFL	
270	20	65	120	-5	100	140	360	145	10
270	20	75	115	-5	90	140	350	150	5
300	5	105	30	-5	75	150	290	150	5
320	15	5	160	85	15	160	190	140	5
320	25	30	135	85	15	180	180	150	0
320	25	105	30	90	20	150	30	160	0
320	25	65	145	95	20	160	135	165	0
350	10	95	160	85	25	110	140	200	75
360	20	120	30	85	30	150	95	220	20
350	30	5	210	90	30	200	100	220	50
375	10	0	250	75	30	140	60	230	20
380	10	140	35	75	30	110	70	230	35
385	5	60	445	100	25	190	150	240	35
390	5	140	480	100	25	150	50	240	35
415	35	130	450	90	35	150	45	250	35
425	60	150	375	90	40	175	50	250	35
440	30	115	50	90	20	175	150	250	35
460	50	150	100	60	95	175	50	250	35
480	30	105	105	60	90	180	35	250	50
475	50	115	50	70	90	150	30	265	20
425	300	105	105	15	110	165	35	250	50
495	20	105	105	10	120	115	30	275	45
500	5	110	45	50	100	120	30	275	25
510	40	105	95	50	125	135	25	630	90
565	40	140	60	65	115	105	10	185	250
565	40	160	65	65	120	160	25	150	325
560	80	120	60	5	160	160	25	290	40
530	230	130	50	5	150	610	15	300	25
-5	100	150	30	50	145	450	300	305	35
90	0	105	10	15	190	325	150	320	35
95	5	105	10	40	170	160	25	320	35
90	30	200	30	605	20	160	25	320	35
90	35	200	50	800	20	160	25	325	25
100	60	215	30	520	240	110	10	325	25
60	90			40	165	105	10	340	50
20	120	D F L		50	140	105	10	355	45
130	10			55	170	120	10	360	50
40	125	675	75	90	200	105	10	360	75
40	125	660	140	85	170	105	10	380	85
40	125	-150	0	100	150	135	10	385	10
40	110	-125	15	25	360	140	10	390	35
40	110	-120	30	0	390	140	10	410	35
130	10	-85	55	130	425	140	10	410	85
60	105	-10	120	175	400	160	10	420	15
65	110	-10	105	180	390	160	10	430	25

Table B-1 Individual Fragment Recovery Data (continued)

DFL

435	35
435	50
450	50
450	30
445	30
450	75
475	50
475	35
460	55
465	45
485	10
500	50
510	30
510	40
540	50
575	20
590	65
580	20
590	80
650	45

D G L

-150	0
-130	10
-70	60
-5	110
90	10
10	90
50	100
55	90
65	95
45	105
50	130
70	130
75	110
15	150
45	145
60	120
140	60
175	30
120	20
230	10
330	20
340	20

DGL

355	85
355	60
370	45
375	55
450	10
490	20
550	125
560	35
575	90
610	50
610	75
630	60
630	230

D H L

-5	80
40	90
40	95
55	90
30	120
0	160
10	165
0	200
15	445
125	35
275	50
355	20
390	50
490	75
490	30
550	270
450	350

D I L

-90	40
-90	40
-85	50
-70	60
-40	110
80	75
85	75
25	95
40	95

DIL

50	95
40	110
45	105
0	150
0	150
0	150
0	160
0	160
15	440
185	100
330	30
395	5

D E R

55	50
60	40
70	15
75	15
75	20
80	25
95	20
120	10
150	40
175	10
185	5
165	20
165	20
165	20
195	40
195	0
225	0
270	20
320	15
320	15
340	40
330	20
330	20
340	10
430	50
525	65

D F R

60	80

DFR

50	50
50	0
50	0
50	40
60	20
60	15
75	45
85	40
85	85
120	0
140	80
140	0
280	40
295	5
300	5
305	40
330	15
325	100
400	50
380	15
380	15
400	15
450	120
510	10
510	15
480	30
480	40
490	30
550	90
575	50
630	70
630	50
110	120

D G R

80	40
260	15
290	10
510	0
300	250
140	120

D H R

50	80

DGR

140	5
300	20
425	55
430	55
430	55
250	250

D I R

50	0
325	5
425	0
595	50
600	50

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